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ELECTRONIC DATABOOK. 3RD ED.
1983.

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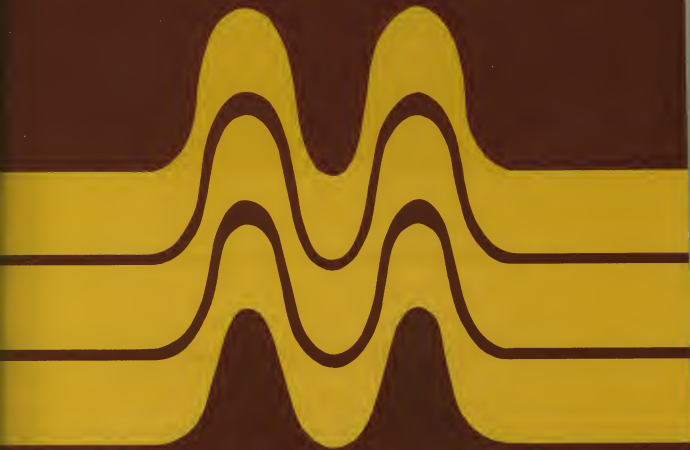




ELECTRONIC DATABOOK

3RD EDITION

Packed with vital, up-to-date facts on every aspect
of electronics practice . . . for hobbyists *and* professionals!



BY RUDOLF F. GRAF



ELECTRONIC DATABOOK

3RD EDITION

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TAB BOOKS Inc.

BLUE RIDGE SUMMIT, PA 17214

BUCKINGHAM

NOV 6 1985

To My Mother and Father

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THIRD EDITION

SECOND PRINTING

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Printed in the United States of America

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Library of Congress Cataloging in Publication Data

Graf, Rudolf F.
Electronic databook.

Includes index.

1. Electronics—Tables. 2. Electronics—Graphic methods. I. Title.

TK7825.G68 1983 621.381'021'2 82-19407

ISBN 0-8306-0138-4

ISBN 0-8306-1538-5 (pbk.)

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The entire electromagnetic spectrum is presented. Then portions of this spectrum that are of particular interest to the electrical and electronic engineer are described in greater detail.	
2. COMMUNICATION	18
Information useful in all segments of communication, starting with propagation characteristics, modes, standards, and transmission data is given. Antenna, transmission line, and waveguide characteristics and performance data are presented. Modulation and international telecommunications standards, signals, signal reporting codes, radio amateur data, and emission information are also given, as is information on microphones.	
3. PASSIVE COMPONENTS AND CIRCUITS	70
Resistors, amplifiers, attenuators, filters, inductors, transformers, and capacitors are covered and their characteristics and applications are treated in depth. Computer-calculated tabulations of modern filter designs based on network synthesis are given.	

4. ACTIVE COMPONENTS AND CIRCUITS

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Vacuum tubes, semiconductors, and integrated circuits are covered. Circuit configurations are given in which these components are employed together with definitions of integrated circuit, logic, and microelectronic terms. A tabulation that shows the characteristics of integrated circuit logic families currently in use is given. Solid-state sensor characteristics and semiconductor memories are covered.

5. MATHEMATICAL DATA, FORMULAS, SYMBOLS

220

This section covers reliability; mathematical signs, symbols, operations, and tables; charts and formulas; prefixes; geometric curves; solids; spherical as well as plane geometry; and trigonometry. Frequency, phase angle, and time relationships for recurrent wave forms are given. Power and voltage level determinations in signals circuits are explained. Letter symbols for all quantities encountered in the electronics, electrical field are defined. This section concludes with a comprehensive selection of conversion factors.

6. PHYSICAL DATA

300

This section covers the most often needed physical data and includes, among other items, laser radiation, motors, radioactivity, optical data, sound, incandescent lamps, cathode ray tubes, crystals, color codes, relay contact code, military nomenclature, atmospheric and space data, chemical data, plastics, temperature and humidity tables, energy conversion factors and equivalents, wire data, hardware, shock and vibration, cooling data, and characteristics of materials.

INDEX

400

Preface

This revised and expanded edition includes a great deal of new material that has come to light since the second edition was published.

The filter section has been thoroughly updated and now includes computer-generated tabulations of modern filter design based on network synthesis. This major entry was especially prepared for this book by Mr. Ed Wetherhold, whose contribution I most gratefully acknowledge.

I also wish to thank my friends and colleagues Rich Myers and F. Raymond Dewey for giving so unselfishly of their time to review and comment on the previous edition of this work and for generously sharing with me much of their private source material.

The word *knowledge* brings to mind the staggering body of facts and data accumulated by mankind since his descent from the trees. Once, thousands of years ago, it was possible for a man to know all that his kind had discovered. But, time has added so greatly to our reservoir of wisdom, that *knowledge*, today, has assumed another meaning: knowing where to find the information needed.

This book humbly admits to being my attempt at simplifying the task of the busy engineer, technician, amateur, and student in locating the data he needs in the shortest possible time.

Gathered here, in one single volume, is a wealth of information in the form of timely and practical nomograms, tables, charts, and formulas.

Some of the material was available elsewhere, at some time or other, but never has all of it been gathered together under one cover. New and heretofore unpublished charts and nomograms are added because of what seemed to me an obvious need for such material.

The book is arranged in a most readily usable format. It contains only clear-cut, theory-free data and examples that are concise, accurate, and to the point. The user of this book will be looking for answers and he will find them, without having to fight his way through lengthy derivations and proofs.

In order to assist you in finding the data you seek, the book has been divided into six functional sections. That organization, together with a comprehensive index, quickly leads to the specific information needed. The

book maintains uniform terminology and format which assures that data found in one section can be easily and accurately related to those in the rest of the book.

Much new and up-dated material has been added to this current edition of the book. It has been my intention (and certainly my hope) that this new material makes the book still more useful and comprehensive.

The preparation of a reference book such as this is not possible without the cooperation and assistance of numerous industry sources who have so generously made their material available. I gratefully acknowledge, with special thanks, the contributions and critical efforts of Messrs. George J. Whalen, Arthur E. Fury, Rene Colen, and B. William Dudley, Jr.

If this book saves you many hours of tedious computations and search for information, it will indeed have served its intended purpose.

The author and publisher invite your comments and suggestions regarding any such other material as might have been included here, so that it may be considered for any subsequent edition or revision.

Acknowledgments

Acknowledgment is made to the following organizations and publications who have permitted use of material originally published by them. I appreciate their cooperation during the preparation of this book.

Alpha Metals, Inc.: page 390.

The American Radio Relay League: pages 55-58, 60, 65 (all from *The Radio Amateur's Operating Manual*, © 1969).

Automatic Electric Company: pages 236-237, 238, 267 (all from *Tables and Formslae*).

Centralab Division of Globe-Union, Inc.: page 99.

Clairex Electronics, Inc. (and J. R. Rabinowitz): page 307.

Computers & Data Processing News: page 227.

Conrad, Inc.: page 358.

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EDN: pages 27 (Nov. 1968); 47 (Sept. 1963); 51 (June 1964); 49 (Nov. 1968); 69 (Nov. 1968); 80 (Nov. 1968); 91 (May 1967); 101 (Sept. 1966); 108 (Nov. 1965); 109 (Apr. 1959); 115 (Jan. 1962); 150 (Oct. 1966); 157 (Nov. 1961); 159 (Sept. 1966); 181 (Sept. 1962); 225 (Nov. 1963); 234 (July 1959); 254 (May 1968); 256 (Dec. 1966); 263 (March, 1977); 284, 285 (Oct. 1960); 311 (Nov. 1962); 312 (Nov. 1962); 365 (May 1963); 383 (Aug. 1978).

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 252-253 (1962); 265, 266 (July 1961); 349 (Nov. 1969).
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Popular Electronics: pages 9, 10 (from *Communications Handbook*, © 1969); page 171.
 PRD Electronics, Inc.: page 48.
 Radio Engineering Laboratories, Inc.: page 21.
 Reynolds Metals Company: pages 246-247, 251 (all from *Facts and Formulas*, © 1961).
 Howard W. Sams & Co., Inc.: page 116 (from *Audio Cyclopeda*, © 1969); pages 173, 190, 369 (from *Referende Data for Radio Engineers*, 5th Edition, © 1968).
 Smithsonian Institution Press: page 317 (from *Smithsonian Physical Tables*).
 Sprague Electric Company: pages 93, 324.
 TAB BOOKS, Inc.: pages 338-339, 389 (from *Master Handbook of Electronic Tables & Formulas* by Martin Clifford, © 1980 BY TAB BOOKS Inc.).
 Testing Machines Inc.: pages 287-299.
 Tilton, Homer B., Visonics Laboratories: page 313.
 TRW, Capacitor Division, page 242.
 Vibrac Corporation: page 379.

ELECTRONIC DATABOOK

3RD EDITION

Section 1

Frequency Data

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THE ELECTROMAGNETIC SPECTRUM

This chart presents an overview of the complete electromagnetic radiation spectrum, extending from infrasonics to cosmic rays. The wavelength, the amount of energy required to radiate one photon, a general description, the band designation, and the normal occurrence or use are given. Some specific bands are described in more detail on the following pages.

$$\lambda_m = \frac{300,000}{f_{\text{kHz}}} = \frac{300}{f_{\text{MHz}}} \quad \lambda_{\text{cm}} = \frac{30}{f_{\text{GHz}}}$$

$$\lambda_R = \frac{984,000}{f_{\text{kHz}}} = \frac{984}{f_{\text{MHz}}} \quad \lambda_{\text{in}} = \frac{11.8}{f_{\text{GHz}}}$$

[illegible]

WAVELENGTH BANDS AND FREQUENCY USED IN RADIOCOMMUNICATION

Nomenclature of the frequency and wavelength bands used in radiocommunication in accordance with Article 2, No. 12 of the "Radio Regulations," Geneva, 1959.

<i>Band Number</i>	<i>Frequency Range (lower limit exclusive, upper limit inclusive)</i>	<i>Corresponding Metric Subdivision</i>	<i>Adjectival Band Designation</i>
1	3- 30 c/s (Hz)	Petametric waves	ELF Extremely-Low Frequency
2	30- 300 c/s (Hz)	Terametric waves	SLF Super-Low Frequency
3	300- 3000 c/s (Hz)	Gigametric waves	ULF Ultra-Low Frequency
4	3- 30 kc/s (kHz)	Myriametric waves	VLF Very-Low Frequency
5	30- 300 kc/s (kHz)	Kilometric Waves	LF Low Frequency
6	300- 3000 kc/s (kHz)	Hectometric waves	MF Medium Frequency
7	3- 30 Mc/s (MHz)	Decametric waves	HF High Frequency
8	30- 300 Mc/s (MHz)	Metric waves	VHF Very High Frequency
9	300- 3000 Mc/s (MHz)	Decimetric waves	UHF Ultra-High Frequency
10	3- 30 Gc/s (GHz)	Centimetric waves	SHF Super-High Frequency
11	30- 300 Gc/s (GHz)	Millimetric waves	EHF Extremely-High Frequency
12	300- 3000 Gc/s (GHz) or 3 Tc/s (THz)	Decimillimetric waves	-----

BROADCASTING FREQUENCY ASSIGNMENTS

This table shows the frequency range, number of available channels, and channel width for AM, FM, and TV service in the United States.

<i>Type of Service</i>	<i>Frequency Range</i>	<i>Number of Available Channels</i>	<i>Width of Each Channel</i>
AM radio	535-1605 kHz	107	10 kHz
FM radio	88- 108 MHz	100	200 kHz
VHF television	54- 72 MHz	12	6 MHz
	76- 88 MHz		
UHF television	174- 216 MHz	70	6 MHz
	470- 890 MHz		

TV CHANNEL FREQUENCIES

TV Channels

Channel Number	Frequency Limits (MHz)	Video Carrier (MHz) Sound Carrier (MHz)
2	54	55.25 59.75
3	60	61.25 65.75
4	66	67.25 71.75
5	72	77.25 81.75
6	76	83.25 87.75
7	88	174 175.25 179.75
8	180	181.25 185.75
9	186	187.25 191.75
10	192	193.25 197.75
11	198	199.25 203.75
12	204	205.25 209.75
13	210	211.25 215.75
14	216	470 471.25 475.75
15	476	477.25 481.75
16	482	483.25 487.75
17	488	489.25 493.75

Channel Number	Frequency Limits (MHz)	Video Carrier (MHz) Sound Carrier (MHz)
18	494	495.25 499.75
19	500	501.25 505.75
20	506	507.25 511.75
21	512	513.25 517.75
22	518	519.25 523.75
23	524	525.25 529.75
24	530	531.25 535.75
25	536	537.25 541.75
26	542	543.25 547.75
27	548	549.25 553.75
28	554	555.25 559.75
29	560	561.25 565.75
30	566	567.25 571.75
31	572	573.25 577.75
32	578	579.25 583.75
33	584	585.25 589.75
34	590	591.25 595.75

Channel Number	Frequency Limits (MHz)	Video Carrier (MHz) Sound Carrier (MHz)
-----596-----		
35		597.25 601.75
-----602-----		
36		603.25 607.75
-----608-----		
37		609.25 613.75
-----614-----		
38		615.25 619.75
-----620-----		
39		621.25 625.75
-----626-----		
40		627.25 631.75
-----632-----		
41		633.25 637.75
-----638-----		
42		639.25 643.75
-----644-----		
43		645.25 649.75
-----650-----		
44		651.25 655.75
-----656-----		
45		657.25 661.75
-----662-----		
46		663.25 667.75
-----668-----		
47		669.25 673.75
-----674-----		
48		675.25 679.75
-----680-----		
49		681.25 685.75
-----686-----		
50		687.25 691.75
-----692-----		
51		693.25 697.75

Channel Number	Frequency Limits (MHz)	Video Carrier (MHz) Sound Carrier (MHz)
-----698-----		
52		699.25 703.75
-----704-----		
53		705.25 709.75
-----710-----		
54		711.25 715.75
-----716-----		
55		717.25 721.75
-----722-----		
56		723.25 727.75
-----728-----		
57		729.25 733.75
-----734-----		
58		735.25 739.75
-----740-----		
59		741.25 745.75
-----746-----		
60		747.25 751.75
-----752-----		
61		753.25 757.75
-----758-----		
62		759.25 763.75
-----764-----		
63		765.25 769.75
-----770-----		
64		771.25 775.75
-----776-----		
65		777.25 781.75
-----782-----		
66		783.25 787.75
-----788-----		
67		789.25 793.75
-----794-----		
68		795.25 799.75

Channel Number	Frequency Limits (MHz)	Video Carrier (MHz) Sound Carrier (MHz)
	-----800-----	
69		801.25 805.75
	-----806-----	
70 (*)		807.25 811.75
	-----812-----	
71		813.25 817.75
	-----818-----	
72		819.25 823.75
	-----824-----	
73		825.25 829.75
	-----830-----	
74		831.25 835.75
	-----836-----	
75		837.25 841.75
	-----842-----	
76		843.25 847.75
	-----848-----	
77		849.25 853.75
	-----854-----	
78		855.25 859.75
	-----860-----	
79		861.25 865.75
	-----866-----	
80		867.25 871.75
	-----872-----	
81		873.25 877.75
	-----878-----	
82		879.25 883.75
	-----884-----	
83		885.25 <u>889.75</u>
	-----890-----	

(*) Channels 70 to 83 were withdrawn and reassigned to TV translator station until licenses expire. License renewals will be granted only a secondary basis for land mobile radio operation.

FREQUENCIES IN USE AROUND THE WORLD IN THE AERONAUTICAL MOBILE BANDS

WORLD AIR ROUTE AREA	FREQUENCY ALLOCATION (kHz)							
Alaska	2945	3411.5	4668.5	5611.5	6567		11,328	
Hawaii		3453.5		5559	6649.5			
West Indies	2861		4689.5					
Central East Pacific		3432.5		5551.5	6612	8879.5	10,048	13,304.5
		3446.5		5604	6679.5	8930.5	10,084	13,334.5
		3467.5					11,299.5	17,926.5
		3481.5					11,318.5	
Central West Pacific	2966			5506.5		8862.5		13,354.5
				5536.5				17,906.5
North Pacific	2987			5521.5		8939		13,274.5
								17,906.5
South Pacific	2945			5641.5		8845.5		13,344.5
								17,946.5
North Atlantic	2868			5611.5		8862.5		13,264.5
	2931			5626.5		8888		13,284.5
	2945			5641.5		8913.5		13,324.5
	2987			5671.5		8947.5		13,354.5
								17,966.5
Europe	2889	3467.5	4654.5	5551.5	6552	8871	11,299.5	17,906.5
	2910	3481.5	4689.5		6582	8930.5		
North-South America	2889	3404.5	4696.5	5566.5	6567	8820	11,290	13,314.5
	2910			5581.5	6664.5	8845.5	11,337.5	13,344.5
	2966					8871		17,916.5
Far East	2868			5611.5		8871		13,284.5
	2987			5671.5		8879.5		13,324.5
						8930.5		17,966.5
South Atlantic	2875	3432.5			6597	8879.5	10,048	13,274.5
					6612	8939		17,946.5
					6679.5			
Middle East		3404.5		5604	6627	8845.5	10,021	13,334.5
		3446.5						17,926.5
North-South Africa	2966	3411.5		5506.5		8820		13,304.5
				5521.5		8956		13,334.5
								17,926.5
								17,946.5
Caribbean	2875			5499	6537	8837	10,021	13,294.5
	2952			5566.5		8871		13,344.5
	2966			5619				17,936.5
Canada	2973			5499		8871	11,356.5	

FREQUENCIES USED BY SHIP AND SHORE STATIONS

Band (MHz)	SHIP STATIONS		SHORE STATIONS
	Calling Frequencies (kHz)	Working Frequencies (kHz)	(Approximate Limits)
2	2065 - 2107	Same as calling	2000 - 2065
4	4178 - 4186	4161 - 4176 4188 - 4236	4240 - 4400
6	6267 - 6279	6241 - 6264 6282 - 6355	6362 - 6523
8	8356 - 8372	8322 - 8352 8376 - 8473	8478 - 8742
12	12,534 - 12,558	12,474 - 12,528 12,564 - 12,709	12,714 - 13,128
16	16,712 - 16,744	16,626 - 16,704 16,752 - 16,946	16,950 - 17,285
22	22,225 - 22,265	22,151 - 22,217 22,272 - 22,395	22,400 - 22,670

INTERNATIONAL AMPLITUDE-MODULATION BROADCASTING FREQUENCIES

5.950- 6.200 MHz
 9.500- 9.775
 11.70 - 11.975
 15.10 - 15.45
 17.70 - 17.90
 21.45 - 21.75
 25.60 - 26.10

AMATEUR RADIO FREQUENCIES

1800 - 2000 kHz	3.300 - 3.500 GHz
3.500 - 4.000 MHz	5.650 - 5.925
7.000 - 7.300	10.00 - 10.50
14.00 - 14.35	24.00 - 24.25
21.00 - 21.45	48.00 - 50.00
28.00 - 29.70	71.00 - 84.00
50.00 - 54.00	152.0 - 170.0
144.0 - 148.0	200.0 - 220.0
220.0 - 225.0	240.0 - 250.0
420.0 - 450.0	Above 275.0
1215 - 1300	
2300 - 2450	

CITIZENS RADIO (PERSONAL RADIO) FREQUENCIES

26.96 27.23 MHz
 462.5375-462.7375
 467.5375-467.7375

COMMONLY USED LETTER-CODE DESIGNATIONS FOR MICROWAVE FREQUENCY BANDS

<i>Band</i>	<i>Frequency</i>	<i>Wavelength</i>	<i>Typical Use</i>
P	225– 390 MHz	133.3– 76.9 cm	Long range (over 200 miles) to very long range (beyond 1,000 miles) surface-to-air search.
L	390–1550 MHz	76.9– 19.3 cm	Very long through medium range surface-to-air missile and aircraft detection, tracking and air traffic control, IFF transponders, beacon systems.
S	1.55– 5.2 GHz	19.3– 5.77 cm	Medium and long range surface-to-air surveillance, surface-based weather radar, altimetry, missile-borne guidance, air-borne bomb-navigation systems.
C	3.9 – 6.2 MHz	7.69– 4.84 cm	Airborne fire control, missile-borne beacons, recon, airborne weather avoidance, aircraft and missile target tracking.
X	5.2–10.9 MHz	5.77– 2.75 cm	Doppler navigation, airborne fire control, airborne and surface-based weather detection, bomb-navigation systems, missile-borne guidance, precision landing approach.
K	10.9– 36 GHz	2.75–0.834 cm	Doppler navigation, automatic landing systems, airborne fire control, radar fuzing, recon, missile-borne guidance.
Q	36– 46 GHz	0.834–0.652 cm	Recon, airport surface detection.
V	46– 56 GHz	0.652–0.536 cm	High-resolution experimental shortrange systems.

CTCS (CONTINUOUS TONE CODED SQUELCH) AND REMOTE CONTROL STANDARD FREQUENCY TABLE

The EIA Standard Tone Frequencies for remote (i.e., radio paging) and control applications have been established to allow adequate separation and minimum harmonic relationship for use in multiple frequency systems.

For optimum system performance it is best to choose the widest frequency spacing possible within the recommended range.

Frequency Hz	EIA Code	Frequency Hz	EIA Code	Frequency Hz	EIA Code
67.0	L 1	258.8	136	651.9	153
71.9	L 2	266.0	106	669.9	123
77.0	L 3	273.3	137	688.3	154
82.5	L 4	280.8	107	707.3	124
88.5	L 4A	288.5	138	726.8	155
94.8	L 5	296.5	108	746.8	125
100.0	1	304.7	139	767.4	156
103.5	1A	313.0	109	788.5	126
107.2	1B	321.7	140	810.2	157
110.9	2	330.5	110	832.5	127
114.8	2A	339.6	141	855.2	158
118.8	2B	349.0	111	879.0	128
123.0	3	358.6	142	903.0	159
127.3	3A	368.5	112	928.1	129
131.8	3B	378.6	143	953.7	160
136.5	4	389.0	113	979.9	130
141.3	4A	399.8	144	1006.9	161
146.2	4B	410.8	114	1049.6	131
151.4	5	422.1	145	1084.0	P
156.7	5A	433.7	115	1120.0	S11
162.2	5B	445.7	146	1190.0	S12
167.9	6	457.9	116	1220.0	S2
173.8	6A	470.5	147	1265.0	S14
179.9	6B	483.5	117	1291.4	S3
186.2	7	496.8	148	1320.0	S15
192.8	7A	510.5	118	1355.0	S16
203.5	M1	524.6	149	1400.0	S17
210.7	M2	539.0	119	1430.5	S7
218.1	M3	553.9	150	1450.0	S18
225.7	M4	569.1	120	1500.0	S20
233.6	M5	582.1	H	1520.0	S9
241.8	M6	600.9	121	1550.0	S21
250.3	M7	617.4	152	1600.0	S22
		634.5	122		

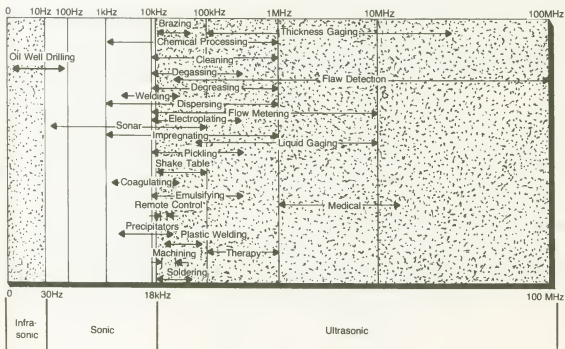
ULTRASONIC TRANSDUCER MATERIALS

The table lists the ultrasonic transducer materials used in instrumentation, sensing and power applications.

Piezoelectric Transducers			
Material	Frequency Range	Maximum Safe Operating Temperature	Typical Applications
Quartz	100 kHz – 35 + MHz	550°C	Medical and non-destructive testing
Barium Titanate	100 kHz – 10 MHz	100°C	Most cleaning and processing applications
Lead Zirconate	5 kHz – 10 MHz	320°C	Most cleaning and processing applications, (high temperature uses)
Lead Titanate			
Rochelle Salt	20 Hz – 1 MHz	45°C	Sonar and depth finding
Magnetostriuctive Transducers			
Nickel	10 kHz – 100 kHz	—	Cleaning, drilling, machining, soldering, melt treatment, and applications where transducer has pressure applied
Venadium Permendur	10 kHz – 100 kHz	—	Same as nickel

ULTRASONIC FREQUENCY SPECTRUM

Ultrasonic Frequency Spectrum



NBS STANDARD FREQUENCY AND TIME BROADCAST SCHEDULES

The diagrams presented here, with explanatory notes, summarize the technical services provided by the National Bureau of Standards (NBS) radio stations WWV, WWVH, WWVB, and WWVL.

WWV and WWVH Broadcast Services

Standard Radio Frequencies. WWV and WWVH transmit frequencies and time coordinated through the Bureau International de l'Heure (BIH), Paris, France. Transmissions are based upon the International time scale, Universal Coordinated Time (UTC).

WWV broadcasts continuously on radio carrier frequencies of 2.5, 5, 10, 15, 20, and 25 MHz. WWVH broadcasts continuously on radio carrier frequencies of 2.5, 5, 10, 15 and 20 MHz.

The broadcasts of WWV may also be heard via telephone by dialing (303) 499-7111, Boulder, Colorado.

Standard Audio Frequencies. Standard audio frequencies of 440 Hz, 500 Hz, and 600 Hz are broadcast on each radio carrier frequency by the two stations. Duration of each transmitted standard tone is approximately 45 seconds. A 600-Hz tone is broadcast during odd minutes by WWV and during even minutes by WWVH. A 500-Hz tone is broadcast during alternate minutes unless voice announcements or silent periods are scheduled. The 440-Hz tone is broadcast beginning one minute after the hour at WWVH and two minutes after the hour at WWV. The 440-Hz tone period is omitted during the first hour of the UTC day.

Standard Musical Pitch. The 440-Hz tone is broadcast for approximately 45 seconds beginning 1 minute after the hour at WWVH and 2 minutes after the hour at WWV. The tone is omitted during the zero hour of each UTC day.

Standard Time Intervals. Seconds pulses at precise intervals are derived from the same frequency standard that controls the radio carrier frequencies. Every minute, except the first of the hour, begins with a 800-millisecond tone of 1,000 Hz at WWV and 1,200 Hz at WWVH. The first minute of every hour begins with an 800-millisecond tone of 1,500 Hz at both stations.

The 1-second markers are transmitted throughout all programs of WWV and WWVH except that the 29th of the 59th markers of each minute are omitted.

Time Signals. The time announcements of WWV and WWVH reference the Coordinated Universal Time Scale maintained by the National Bureau of Standards, UTC(NBS).

The 0 to 24 hour system is used starting with 0000 for midnight at the Greenwich Meridian (longitude zero). The first two figures give the hour, and the last two figures give the number of minutes past the hour when the tone returns.

At WWV a voice announcement of Greenwich Mean Time is given during the 7.5 seconds immediately preceding the minute.

At WWVH a voice announcement of Greenwich Mean Time occurs during the period 15 seconds to 7.5 seconds preceding the minute. The voice announcement for WWVH precedes that of WWV by 7.5 seconds. However, the tone markers referred to in both announcements occur simultaneously.

Propagation Forecasts. A forecast of radio propagation conditions is broadcast in voice from WWV at 14 minutes after every hour. The announcements are short-term forecasts and refer to propagation along paths in the North Atlantic area, such as Washington, D.C. to London or New York to Berlin.

The propagation forecast announcements are repeated in synoptic form comprised of a phonetic and a numeral. The phonetic (Whiskey, Uniform, or November) identifies the radio quality at the time the forecast is made. The numeral indicates on a scale of 1 to 9 the radio propagation quality expected during the six-hour period after the forecast is issued. The meaning of the phonetics and numerals are:

<i>Phonetic</i>	<i>Meaning</i>
Whiskey	disturbed
Uniform	unsettled
November	normal

<i>Numeral</i>	<i>Meaning</i>
One	useless
Two	very poor
Three	poor
Four	poor-to-fair
Five	fair
Six	fair-to-good
Seven	good
Eight	very good
Nine	excellent

If, for example, propagation conditions are normal and expected to be good during the next six hours, the coded forecast announcement would be "November Seven."

Geophysical Alerts. Current geophysical alerts (Geoalerts) as declared by the World Warning Agency of the International Ursigram and World Days Service (IUWDS) are broadcast in voice from WWV at 18 minutes after each hour and from WWVH at 45 minutes after each hour.

Weather Information. Weather information about major storms in the Atlantic and Pacific areas is broadcast from WWV and WWVH respectively.

Time Code. The time code is transmitted continuously by both WWV and WWVH on a 100-Hz subcarrier. The code format is a modified IRIG-H time code produced at a 1-pps rate and carried on 100-Hz modulation. The 100-Hz subcarrier is synchronous with the code pulses so that 10-millisecond resolution is readily obtained.

The code contains UTC time-of-year information in minutes, hours, and day of year. Seconds information may be obtained by counting pulses.

The binary coded decimal (BCD) system is used. Each minute contains seven BCD groups in this order: two groups for minutes, two groups for hours, and three groups for day of year. The code digit weighting is 1-2-4-8 for each BCD group multiplied by 1, 10, or 100 as the case may be. A complete time frame is 1 minute. The binary groups follow the 1-minute reference marker.

Modulation. At WWV and WWVH, double sideband amplitude modulation is employed with 50 percent modulation on the steady tones, 25 percent for the IRIG-H code, 100 percent for seconds pulses, and 75 percent for voice.

WWVB Broadcast Services

WWVB transmits a standard radio frequency, standard time signals, time intervals, and UT1 corrections. The station is located near WWV on the same site.

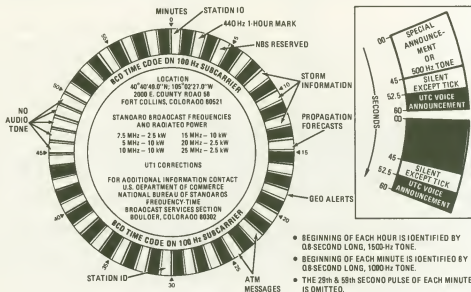
Program. WWVB broadcasts a standard radio carrier frequency of 60 kHz with no offset. It also broadcasts a time code consistent with the internationally coordinated time scale UTC(NBS).

WWVL Experimental Broadcasts

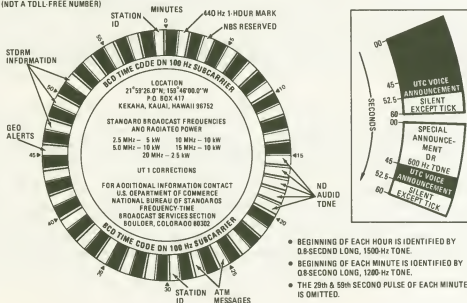
WWVL broadcasts experimental programs, usually involving multiple frequencies. The station is located in the same building with WWVB and on the same site with WWV.

Effective On UTC, 1 July 1972, regularly scheduled transmissions from WWVL were discontinued. Contingent upon need and availability of funds this station broadcasts experimental programs on an intermittent basis only.

WWVL transmits only carrier frequencies with no modulation. The format and frequencies used by WWVL are subject to change to meet the requirements of the particular experiment being conducted.



VIA TELEPHONE: (800) 335-4214
(NOT A TOLL-FREE NUMBER)



WAVELENGTH-FREQUENCY CONVERSION SCALE

This scale is based on the formula

$$\lambda_m = \frac{300}{f_{MHz}}$$

It shows the relationship between free space wavelength λ and frequency f and covers a frequency range extending from 300 Hz to 300 GHz, corresponding to wavelengths of 1000 m (1 km) to 1 mm.

FOR EXAMPLE: A 60-MHz signal has a wavelength of 5 m. A signal whose wavelength is 3 mm has a frequency of 100 GHz.

Frequency Wavelength
GHz — millimeter (mm)
MHz — meter (m)
kHz — kilometer (km)



Section 2

Communication







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PROPAGATION CHARACTERISTICS OF ELECTROMAGNETIC WAVES

<i>Band</i>	<i>Frequency (Wavelength)</i>	<i>Characteristics</i>	<i>Applications</i>
Very-low frequency (VLF)	20-30 kHz (20,000-10,000 m)	Very stable; low attenuation at all times. Influenced by magnetic storms. Ground wave extends over long distances. (No fading out long-time variations occur.)	Continuously operating long-distance station-to-station communication service.
Low frequency (LF)	30-300 kHz (10,000-1,000 m)	Seasonal and daily variations greater than that of VLF; daytime absorption also greater, increasing with frequency. At night similar to VLF although slightly less reliable.	Long-distance station-to-station service (marine, navigational aids).
Medium frequency (MF)	300-3,000 kHz (1,000-100 m)	Less reliable over long distances than lower frequencies. Attenuation: low at night, high in daytime; greater in summer than in winter. Low attenuation at night is due to sky-wave reflection. Ground-wave attenuation is relatively high over land and low over salt water.	Commercial broadcasting police, marine and airplane navigation.
High frequency (HF)	3-30 MHz (100-10 m)	Dependent on ionospheric conditions, leading to considerable variation from day to night and from season to season. Attenuation low under favorable conditions, and high under unfavorable conditions, at medium to very long distances.	Medium and long-distance communication service of all types.
Very-high frequency (VHF)	30-300 MHz (10-1 m)	30-60 MHz sometimes affected by ionosphere. Quasi-optical transmission (similar to light, but subject to diffraction by surface of the earth).	Television, FM commercial broadcasting, radar airplane navigation, short-distance communications.
Ultra-high frequency (UHF)	300-3,000 MHz (100-10 cm)	Substantially same as above; slightly less diffraction. Under abnormal conditions, can be refracted by troposphere similar to sky-wave refraction. This often results temporarily in abnormally long ranges of transmission.	Television, radar, microwave relay, short-distance communications.
Super-high frequency (SHF)	3,000-30,000 MHz (10-1 cm)	Same as above. 1-cm range has broad water-vapor absorption band (slight O ₂ absorption).	Radar, microwave relay, short distance communications.

COMMUNICATION MODES

Principal ground-to-ground communication modes, utilizing the microwave (70 MHz to 20 GHz) region of the spectrum. Characteristically wide-band (100 kHz to 20 MHz) service.

 <p>LINE OF SIGHT (LOS)</p>	<p>0 to 35 miles, depending on (h).</p>	<p>0.1 to 10W, two to 10-ft antennas</p>	<p>Low-cost, high-performance wide-band system; replaces costly right-of-way maintenance of coaxial or multiple cable or overhead wiring.</p>
 <p>LOS Space Communications</p>	<p>upto 1/2 circum- ference of earth depending on satellite orbit and (Θ)</p>	<p>1 to 15 kW, 30 to 85-ft antennas</p>	<p>Only practical system of global coverage using three active synchronous satellites (22,000 miles from earth) or a number of orbiting satel- lites (dependent on distance covered and altitude) in con- junction with multiple earth earth stations.</p>
 <p>DIFFRACTION (Plane Surface)</p>	<p>30 to 70 miles, depending on (h) and N_B</p>	<p>0.1 to 100W, six to 28-ft antennas</p>	<p>Diffraction mode is very specialized form of UHF used only rarely where rugged terrain prevents use of direct LOS and permits longer path with obstacle gain.</p>
 <p>DIFFRACTION (Knife Edge)</p>	<p>30 to 120 miles, depending on (h), (N_B) and (G_O)</p>	<p>0.1 to 100W, six to 28-ft antennas</p>	<p>Great attention is being given to refining propagational computation in the diffrac- tion region because of need for utilization in tropo path predictions.</p>
 <p>DIFFRACTION (Rough Surface)</p>	<p>30 to 120 miles, depending on (h), (N_B), (G_O), and (A_O)</p>	<p>0.1 to 100W, six to 28-ft antennas</p>	<p>Great attention is being given to refining propagational computation in the diffrac- tion region because of need for utilization in tropo path predictions.</p>
 <p>Scatter Region LOS DIFF DIFF LOS TROPO</p>	<p>70 to 600 miles, depending on many factors</p>	<p>1 to 100 kW, 10 to 120-ft antennas, refined modula- tion and receiver techniques</p>	<p>Only practical wide-band, reliable ground-based method of achieving 70 to 600 mile hop where unsuitable inter- vening territory prevents use of LOS or diffraction modes.</p>

(h) = height of antenna center
(N_B) = refractive index
(G_O) = obstacle gain

(A_O) = obstacle absorption
(d) = distance between stations
(Θ) = bearing angle or angle of elevation

INTERNATIONAL TELEVISION STANDARDS

This table outlines pertinent characteristics of the current TV standards used throughout the world. The video frequency-channel arrangements are also shown. The systems have been designated by letter and are in use or proposed for use in the countries listed.

Country	Standard Used ^c	Country	Standard Used ^c
Argentina	N	Mexico	M
Australia	B	Monaco	E, G
Austria	B, G	Morocco	B
Belgium	C, H	Netherlands	B, G
Brazil	M	Netherlands Antilles	M
Bulgaria	D, K	New Zealand	B
Canada	M	Nigeria	B
Chile	M	Norway	B
China	D	Pakistan	B
Colombia	M	Panama	M
Cuba	M	Peru	M
Czechoslovakia	D	Philippines	M
Denmark	B	Poland	D
Egypt	B	Portugal	B, G
Finland	B, G	Rhodesia	B
France	E, L	Romania	K
Germany (East)	B	Saudi Arabia	M
Germany (West)	B, G	Singapore	B
Greece	B	South Africa	I
Hong Kong	B, I	Spain	B, G
Hungary	D, K	Sweden	B, G
India	B	Switzerland	B, G
Iran	B	Turkey	B
Ireland	A	United Kingdom	A, I
Israel	B	United States of America	M
Italy	B, G	Union of Soviet Socialist Republics	D
Japan	M	Uruguay	N
Korea	C, L	Yugoslavia	B, G
Luxembourg	F		

^cLetter designations correspond to those in the following table.

	A	M	N	B	C	G	H	I	D, K	L	F	E			
Lines/frame	405	525	625	625	625	625	625	625	625	625	819	819			
Fields/sec	50	60	50	50	50	50	50	50	50	50	50	50			
Interlace	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1	2/1			
Frames/sec	25	30	—	25	25	25	25	25	25	25	25	25			
Lines/sec	10	125	15	750	—	15	625	15	625	15	625	20	475	20	475
Aspect ratio ¹	4/3	4/3	—	4/3	4/3	4/3	4/3	4/3	4/3	4/3	4/3	4/3			
Video band (MHz)	3	4.2	4.2	5	5	5	5	5.5	6	6	5	10			
RF band (MHz)	5	6	6	7	7	8	8	8	8	8	7	14			
Visual polarity ²	+	—	—	—	+	—	—	—	—	+	+	+			
Sound modulation	A3	F3	—	F3	A3	F3	F3	F3	F3	F3	A3	A3			
Pre-emphasis in microseconds	—	75	—	50	50	50	50	50	50	—	50	—			
Deviation (kHz)	—	25	—	50	—	50	50	50	50	—	—	—			
Gamma of picture signal	0.45	0.45	—	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6			

Notes:

¹ In all systems the scanning sequence is from left to right and top to bottom.

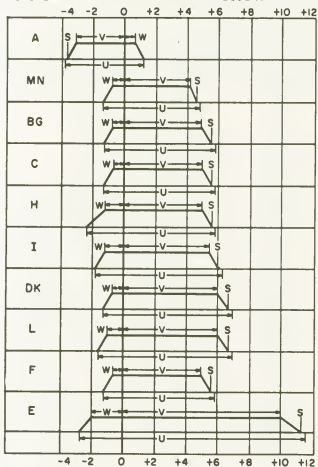
² All visual carriers are amplitude modulated. Positive polarity indicates that an increase in light intensity causes an increase in radiated power. Negative polarity (as used in the US—Standard *M*) means that a decrease in light intensity causes an increase in radiated power.

Notes:

¹ In all systems the scanning sequence is from left to right and top to bottom.

² All visual carriers are amplitude modulated. Positive polarity indicates that an increase in light intensity causes an increase in radiated power. Negative polarity (as used in the US—Standard M) means that a decrease in light intensity causes an increase in radiated power.

SYSTEM FREQUENCY RELATIVE TO THE
VIDEO CARRIER FREQUENCY



S = SOUND CARRIER
 U = LIMITS OF RADIO-FREQUENCY CHANNEL
 V = NOMINAL WIDTH OF MAIN SIDEBAND
 W = NOMINAL WIDTH OF VESTIGIAL SIDEBAND

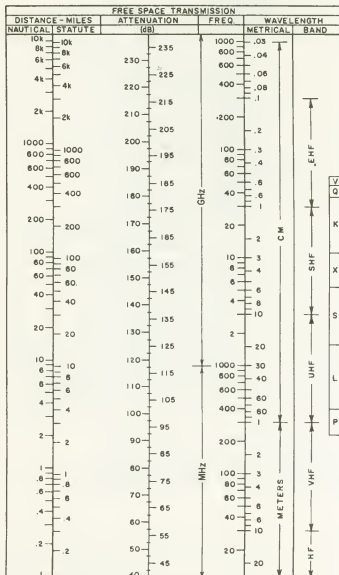
FREE SPACE TRANSMISSION NOMOGRAM

This nomogram relates receiver-transmitter distance, wavelength and free space attenuation. It can also be used to convert between nautical and statute miles and between frequency and wavelength.

FOR EXAMPLE: A signal from a 200-MHz transmitter will be attenuated 125 dB before it reaches a receiver located 100 nautical miles away.

At a distance of 200 nautical miles, and a system gain of 130 dB, the highest usable frequency is 180 MHz.

The maximum distance between a transmitter-receiver-antenna system with a total gain of 125 dB operating at 500 MHz is 45 statute miles.

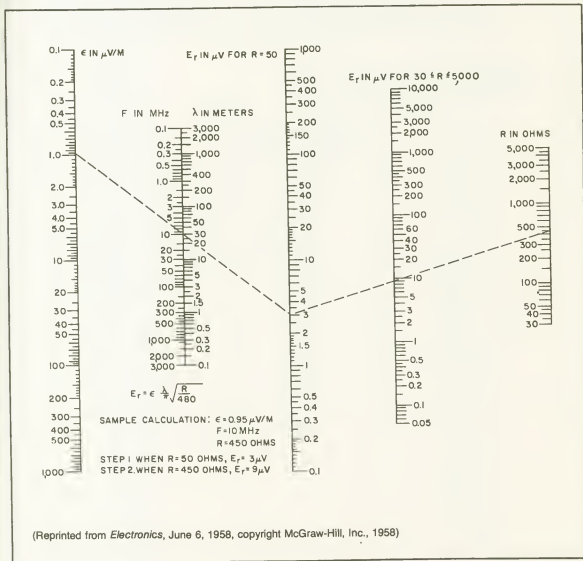


SIGNAL-STRENGTH NOMOGRAM

This nomogram is used to compute signal-strength input at the receiver based on a formula that converts field intensity at the receiving antenna to receiver input voltage.

If field intensity ϵ , in microvolts per meter, of a given signal f , in MHz, is known, the signal strength E_r , in microvolts, is determined for an input impedance of 50 ohms (E_r in μV for $R = 50$) and may be adjusted for any value of input impedance between 30 and 5000 ohms (E_r in μV for $30 \leq R \leq 5,000$). An isotropic antenna, no-loss transmission line is assumed.

Signal strength for receiving antennas of gain > 1 (0 dB) are solved first by finding from the chart the voltage input for a system with an isotropic antenna and then adjusting the answer using the relation: $G = 20 \log (E'_r / E_r)$ where G is the gain of the antenna referred to isotropic; E'_r is the voltage input to be found; and E_r is the voltage input.

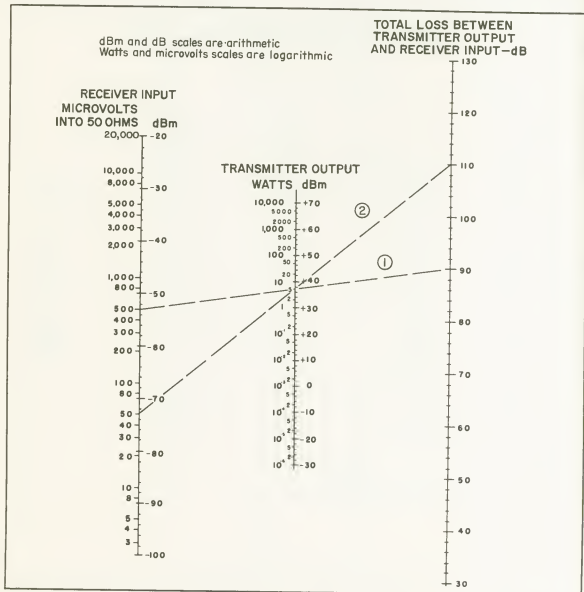


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NOMOGRAM RELATING TRANSMITTER OUTPUT, TRANSMISSION LOSS, AND RECEIVER INPUT

This nomogram shows the available input voltage (microvolts into 50 ohms), if transmitter output in watts and transmission loss in decibels are known. It can also show the maximum permissible transmission loss if transmitter power and receiver requirements are given, or it can be used to determine the required transmitter output for a given transmission loss and receiver input voltage. Microvolts (into 50 ohms) may be directly converted to dBm on the left scale and watts may be converted to dBm on the center scale.

FOR EXAMPLE: (1) For a transmitter output of 5W and a transmission loss of 90 dB, the receiver input will be 500 μ V. (2) For a minimum of 50 μ V at the receiver, and a transmitter output of 5W, the transmission loss may not exceed 110 dB.



RECEIVER BANDWIDTH-SENSITIVITY-NOISE FIGURE NOMOGRAM

This nomogram is based on the noise figure of a receiver as given by the equation:

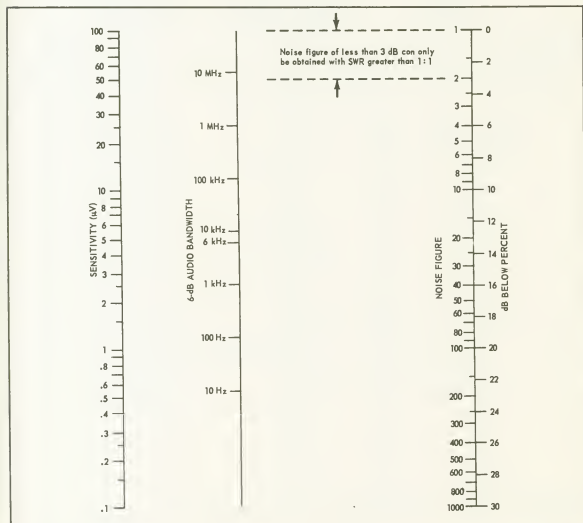
$$NF = \frac{(mE_o \sqrt{P_n/P_s})^2}{2R(4KT\Delta f)}$$

where NF = noise figure; m = modulation index; P_n = noise power; P_s = signal power; K = Boltzmann's constant or 1.38×10^{-23} joules/°K; R = antenna resistance; T = degrees Kelvin; Δf = 6-dB audio bandwidth, and E_o = signal generator output in μV .

Nominal antenna impedance is 52 ohms and the temperature can be approximated at 300°K.

To find the noise figure of a receiver, it is only necessary to place a straightedge across the sensitivity and audio bandwidth points, extending it to intersect the noise figure line.

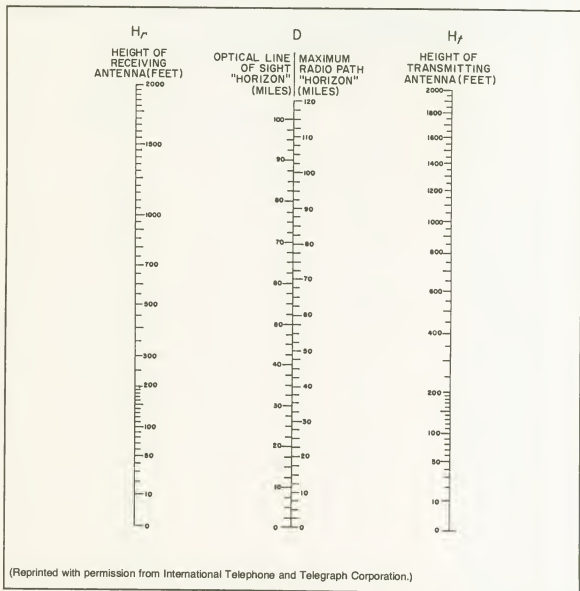
FOR EXAMPLE: Sensitivity of 10 μV and bandwidth of 6 kHz gives a noise figure of 100, or 20 dB.



LINE-OF-SIGHT TRANSMISSION RANGE NOMOGRAM SHOWING THE APPROXIMATE TRANSMISSION RANGE OF SIGNALS IN THE VHF BAND

The theoretical maximum distance that can be covered is equal to the geometrical or "optical" horizon distance of each antenna, and is defined by the formula $D = 1.23 \sqrt{H_r} + 1.23 \sqrt{H_t}$, where D is in miles and H_r and H_t are the height in feet, above effective ground level, of the receiving and transmitting antennas. Atmospheric diffraction increases the distance by a factor of $2 \sqrt{3}$ which defines the "radio" path under normal or standard diffraction, by the formula $D = 1.41 \sqrt{H_r} + 1.41 \sqrt{H_t}$.

FOR EXAMPLE: With a receiving antenna height of 30 ft and a transmitting antenna height of 100 ft, the "optical" horizon is 19 miles and the "radio" horizon is 21.5 miles.



RADAR POWER-ENERGY NOMOGRAM

The energy available from a radar transmitter is often the limiting factor in determining the maximum free space range. This nomogram relates the four interdependent radar equations involving peak power, average power, energy, duty cycle, pulse width, pulse repetition rate and pulse interval based on the following equations:

$$\frac{P_{AV}}{P_P} = d = \tau f, \text{ and } P_P \tau = E = P_{AV} t$$

where P_P = peak power in watts

P_{AV} = average power

E = energy in joules

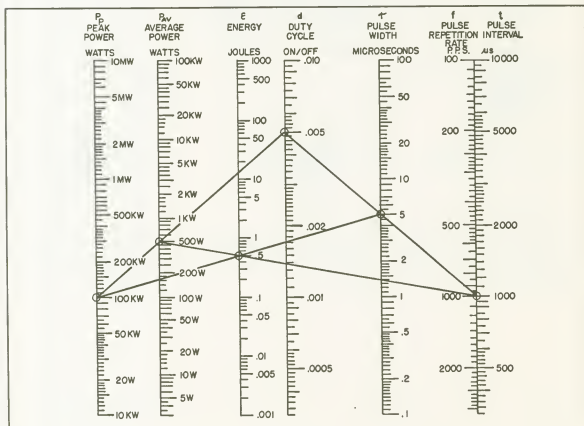
d = duty cycle

τ = pulse width in microseconds

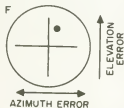
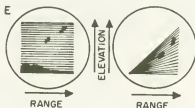
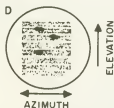
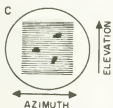
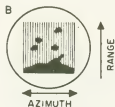
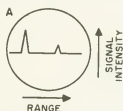
f = pulse repetition rate in pulses/sec

t = pulse interval in microseconds

FOR EXAMPLE: A pulse repetition rate of 1,000 pulses/sec with a pulse width of 5 μ sec will give a duty cycle of 0.005. For a peak power of 100 kW, join this value on the P_P scale with 0.005 on the duty-cycle scale and read an average power of 500 W. Joining the 100 kW point with the pulse width of 5 μ sec shows the energy as 0.5 J. (To crosscheck, connect the average power of 500 W with 1,000 pps rep rate, which also yields 0.5 J.)

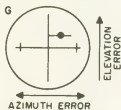


TYPES OF RADAR INDICATORS

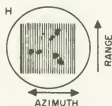


Coarse range information is provided by position of signal in broad azimuthal trace.

Single signal only. In the absence of a signal, the spot may be made to expand into a circle



Single signal only. Signal appears as "wingspot," position giving azimuth and elevation errors. Length of wings inversely proportional to range.



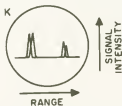
Signal appears as two dots. Left dot gives range and azimuth of target. Relative position of right dot gives rough indication of elevation.



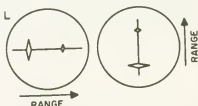
Antenna scan is conical. Signal is a circle, the radius proportional to range. Brightest part indicates direction from axis of cone to target.



Same as type A, except time base is circular, and signals appear as radial pips.



Type A with lobe-switching antenna. Spread voltage splits signals from two lobes. When pips are of equal size, antenna is on target.



Same as type K, but signals from two lobes are placed back to back.



Type A with range step or range notch. When pip is aligned with step or notch, range can be read from a dial or counter.



A combination of type K and type M.



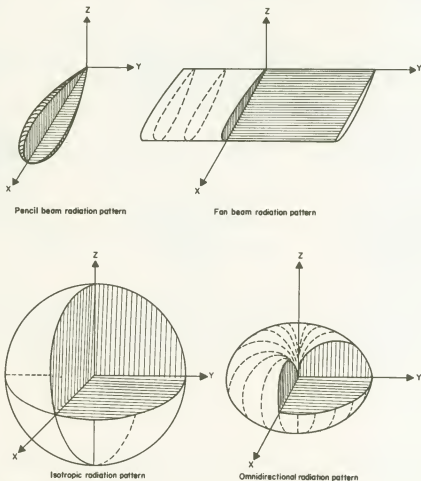
Range is measured radially from the center.

ANTENNA REFERENCE CHART

Antennas may be classified as linear radiators or elements, apertures arrays, and traveling wave types. Basic information on a few types of antennas is tabulated. For each type the following is given: the antenna name, physical size in wavelengths, a line drawing superimposed on coordinate axis, the impedance R in ohms at the resonant frequency f_r , the half-power (3 dB) bandwidth in percent, the gain in dB above an isotropic radiator, as well as the conventional half-wavelength dipole, the polarization for the given configuration, and a set of Fraunhofer Zone field strength patterns for each of the three orthogonal planes of the axis system shown.

An isotropic radiator is given, even though such an antenna for electromagnetic waves does not exist. It is a convenient and frequent reference, however, for gain and pattern measurements.

The antennas tabulated may be vertically or horizontally polarized radiators. The configuration shown in the chart is the one most frequently used in practice. The antennas listed may be fed by balanced transmission lines, by coaxial lines and a balun (balanced-to-unbalanced transformer) when necessary, or in some cases by waveguides. Aperture antennas, such as parabolic dishes and horns, are usually fed by waveguides and, for such feed systems, impedance is not too meaningful.



Broadside Array

$$L = \lambda/2$$

polarization: vertical

Theoretical Gain of Broadside $\frac{1}{2} \lambda$ elements at different spacings "a".

Spacing in wavelengths "a"	Gain, dB above Dipole
$\frac{1}{2}$	4.8
$\frac{3}{4}$	4.6
$\frac{1}{2}$	4.0
$\frac{3}{8}$	2.4
$\frac{1}{4}$	1.0
$\frac{1}{8}$	0.3



Theoretical Gain of Broadside $\frac{1}{2} \lambda$ elements for different numbers of elements.

Number of elements	Gain, dB above Dipole
2	4.0
3	5.5
4	7.0
5	8.0
8	9.0

End Fire Array

$$L = \lambda/2$$

polarization: vertical

Theoretical Gain of Two End Fire $\frac{1}{2} \lambda$ Elements for Various Spacings "a"

a	Gain, dB above Dipole
$\frac{1}{2}$	1.7
$\frac{1}{2}$	2.2
$\frac{3}{4}$	3.0
$\frac{1}{2}$	3.8
$\frac{1}{20}$	4.1
$\frac{1}{8}$	4.3



Parasitic Array

$$L = \lambda/2$$

polarization: horizontal

Number of Elements	Gain, dB above Dipole	Front to Back Ratio, dB
2	4 to 5	10 to 15
3	8 to 7	15 to 25
4	7 to 9	20 to 30
5	9	—



Collinear Array

$$L = \lambda/2$$



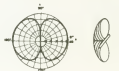

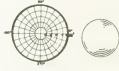



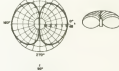







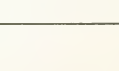

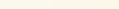



$$b = \lambda/4$$

Spacing "a" between centers of adjacent $\frac{1}{2} \lambda$ elements

Number of $\frac{1}{2} \lambda$ elements in array versus gain in dB above a reference Dipole	2	3	4	5	8
$a = \frac{1}{2} \lambda$	1.8	3.3	4.5	5.3	8.2
$a = \frac{3}{4} \lambda$	3.2	4.8	8.0	7.0	7.8



TYPE	CONFIGURATION	IMPEDANCE Relative at E, F , ohms	BANDWIDTH%	GAIN db above		POLARIZATION	PATTERN #	PATTERN TYPES	
				Isotropic	Dipole				
Isotropic Radiator (theoretical)		—	—	0	-2.14	none	A		
Small Dipole $L < \lambda/2$		very high	very small	1.74	-0.4	H	B		
Thin Dipole $L = \lambda/2$ $L/D = 275$		60	34	2.14	0	H	B		
Thick Dipole $L = \lambda/2$ $L/D = 51$		49	55	2.14	0	H	B		
Cylindrical Dipole $L = \lambda/2$ $L/D = 10$		37	100	2.14	0	H	B		
Folded Dipole $L = \lambda/4$ $L/d = 13$		6000	5	1.64	-0.5	H	B		
Folded Dipole $L = \lambda/2$ $L/d = 25.5$		300	45	2.14	0	H	B		
Cylindrical Dipole $L = \lambda$ $L/D = 9.6$		150	130	3.64	1.5	H	B		
Biconical $L = \lambda/2$		72	100	2.14	0	H	B		
Biconical $L = \lambda$		350	200	2.14	0	H	B		
Turnstile $L = \lambda/2$ $L/d = 25.5$		150	50	-0.86	-3	H	C		
Folded Dipole over reflecting sheet $L = \lambda/2$ $L/d = 25.5$ $\lambda/4$ above sheet		150	20	7.14	5	H	D		

PATTERN #	POLARIZATION	GAIN db above		BANDWIDTH %	IMPEDANCE Resistive at f_r , ohms	CONFIGURATION	TYPE
		Dipole	Isotrope				
	E	V	0	2.14	40	28	 Dipole over small ground plane $L = \lambda/4$ $L/D = 53$ $l = 2\lambda$
	E	V	0	2.14	45	150	 Folded Unipole over small ground plane $L = \lambda/4$ $L/D = 53$ $l = 2\lambda$ $L/d = 13$
	E	V	0	2.14	16	50	 Coaxial Dipole $L = \lambda/4$ $L/D = 40$
	E	V	0	2.14	200	72	 Biconical Coaxial Dipole $L = \lambda/2$ $d = \lambda/8$ $D = 3\lambda/8$
	E	V	0	2.14	300	50	 Disc-Cone or Rod Disc-Cone $L = \lambda/4$ $l = \lambda$
	E	V	12	14.14	25	20	 Biconical Horn $L = 0\lambda/2$ $D = 14\lambda$
	F	H	0	2.14	70	350	 Slot in Large Ground Plane $L = \lambda/2$ $l/d = 20$
	B	H	1	3.14	13	45	 Vertical Full Wave Loop $D = \frac{\lambda}{\pi}$ $D/d = 36$
	G	Circ.	8	10.14	200	130	 Helical over reflector screen, tube 6λ long coiled into 6 turns $\lambda/4$ apart
	H	H	14.5	16.74	100	600	 Rhombic $L = 0\lambda$ $l = 0\lambda/2$
	H	H	12.5	14.74	30	300	 Parabolic with folded dipole feed ($\lambda/2$) $D = 0\lambda/2$
	H	H	13	15.14	35	50	 Horn, coaxial feed $l = 3\lambda$ $L = 3\lambda$

MICROWAVE ANTENNA CHART

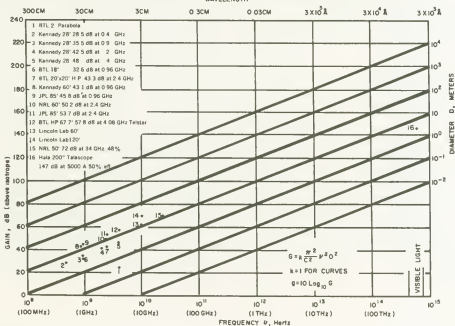
Shown here is the relationship between circular antenna aperture size, frequency, and gain. Also listed are the antenna performance requirements for various system applications. Practical factors, such as whether the antenna is solid or perforated, the type of aperture illumination, accuracy of construction, and shadowing from the feed system will tend to reduce the gain somewhat.

FOR EXAMPLE: To achieve a gain of 40 dB at 10 GHz requires an antenna with a diameter of 10 m. An antenna with a diameter of 100 m has a gain of 100 dB at 100 GHz.

Antenna Performance Requirements

APPLICATION	PATTERN	POLARIZATION	GAIN S, (dB) above isotropic rad.	BEAMWIDTH (H): degree	POINTING ACCURACY, to degree	TYPICAL TYPES
1. SATELLITE Link or Probe	Pencil Beam	any	10 to 40 dB or more	60 to 2 or less	8 to .2 or better	Horn, Phased array, Parabola, Cassegrain
2. POINT TO POINT RELAY a. On Earth b. Earth to Satellite c. Satellite to Satellite	Pencil Beam	any	a. 50 to 120 b. 50 to 120 c. 50 to 160	a. 5.8×10^{-1} to 1.8×10^{-4} b. 5.8×10^{-1} to 1.8×10^{-9}	5.8×10^{-3} to 1.8×10^{-7}	Horn, Parabola, Cassegrain
3. BROADCAST a. Earth Trans. b. Sat. Trans.	omnidir. wide or fan beam	any	a. 3 to 40 b. 1 to 10	100 to 1.8 180 to 60	10 to .18	a. Vertical radiator b. Cylindrical parabola
4. NAVIGATION	omnidir. or fan beam	any	3 to 50	100 to .58	10 to .058	Vertical radiator, Horn, or Parabola
5. RADAR a. Search b. Track	cscd Pencil Beam	any	40 to 120	1.8 to 1.8×10^{-4}	.18 to 1.8×10^{-5}	Horn, Parabola, Cassegrain, Phased array
6. RADIO ASTRONOMY a. Passive b. Active	Pencil Beam	any	50 to 160 or greater	.58 to 1.8×10^{-8}	.037 to 1.8×10^{-7}	Parabola, Cassegrain, Phased array
7. RADIO METEY Industrial	any	any	unknown	unknown	unknown	Any

Antenna Gain and Size vs Frequency for Uniformly Illuminated Circular Aperture



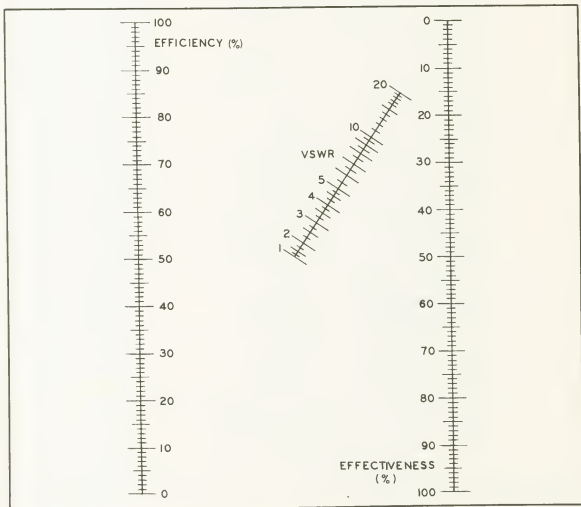
ANTENNA EFFECTIVENESS NOMOGRAM

Antennas are judged on the basis of radiation efficiency or their VSWR. Radiation efficiency is the ratio of the radiated power to the total power fed into the antenna terminals. Total power is the sum of the radiated power and the power lost in ohmic losses in the form of heat. The power going into the antenna terminals is the power which a transmitter can put out less the power reflected due to antenna mismatch. Antenna effectiveness is the ratio of the radiated power to the power which a transmitter can put into a matched load, i.e., the forward or incident power.

$$\text{Effectiveness} = \frac{4 \text{ VSWR}}{(\text{VSWR} + 1)^2} \times \text{efficiency}$$











FOR EXAMPLE: A 60% efficient antenna with a 2.5:1 VSWR has an effectiveness of 48% compared to a perfectly matched 100% efficient antenna.

NOTE: In some cases an antenna can be made more effective by lessening its efficiency if this will produce a sufficient reduction in the VSWR.



TRANSMISSION LINE CHARACTERISTICS

Characteristics of Various Types of Transmission Lines Erected Parallel to a Perfectly Conducting Earth.

LOGARITHMS TO THE BASE 10		$I_1 = \text{GENERATOR CURRENT}$	
LINE CONFIGURATION	CHARACTERISTIC IMPEDANCE	NET GROUND-RETURN CURRENT	
Single wire 	$Z_0 = 138 \log \frac{2h}{r}$	$I_{\text{Gnd}} = I_1$	
2-Wire balanced 	$Z_0 = 276 \log \frac{s}{r}$	$I_{\text{Gnd}} = 0$	
2-Wire 1 wire grounded 	$Z_0 = 276 \frac{\log \frac{s}{r} \log \left(\frac{s^2}{r^2} \right)}{\log \left[\rho^2 \left(\frac{s}{r} \right)^2 \right]}$ $\rho = \frac{2h}{s}$	$I_{\text{Gnd}} \approx I_1 \frac{\log \frac{s}{r}}{\log \frac{2h}{r}}$	
3-Wire 2 wires grounded 	$Z_0 = 69 \left[\log \frac{s}{2r} - \frac{(\log \frac{s}{2r})^2}{\log \frac{2h}{r}} \right]$	$I_{\text{Gnd}} \approx I_1 \frac{\log \frac{s}{r}}{\log \frac{2h}{r}}$ $\rho = \frac{2h}{s}$	
4-Wire balanced 	$Z_0 = 138 (\log \frac{s}{r}) - 21$	$I_{\text{Gnd}} = 0$	
4-Wire 2-wires grounded 	$Z_0 = 138 \left[\frac{\log \frac{s}{r} \log \left(\rho^4 \frac{s}{r} \right)}{\log \left[\rho^4 \left(\frac{s}{r} \right)^2 \right]} \right]$ $\rho = \frac{2h}{s}$	$I_{\text{Gnd}} \approx I_1 \frac{\log \frac{s}{r}}{\log \frac{\rho^2 s}{r}}$	
5-Wire 4 wires grounded 	$Z_0 = 138 \left[\log \frac{2h}{r} - \frac{(\log 2\rho)^2}{\log \left(\frac{s^2 h^2}{r^2} \right)} \right]$ $\rho = \frac{2h}{s}$	$I_{\text{Gnd}} \approx I_1 \frac{\log \frac{s}{r}}{\log \frac{s \rho^4}{r}}$	
Concentric (coaxial) 	$Z_0 = 138 \frac{\log \frac{b}{a}}{\sqrt{1 + (\frac{b}{a})^2} \omega}$ $\epsilon = \text{Dielectric constant of insulating material}$		
Double coaxial balanced 	$Z_0 = 276 \frac{\log \frac{b}{a}}{\sqrt{1 + (\frac{b}{a})^2} \omega}$		
Shielded pair balanced 	$Z_0 = \frac{120}{\sqrt{\epsilon}} \left[2.303 \log \left(2\sqrt{\frac{1+\sigma^2}{1-\sigma^2}} \right) - \frac{1+4\sqrt{1-\sigma^2}}{16\sqrt{4}} (1-4\sigma^2) \right]$ $\epsilon = \text{Dielectric constant of medium}$ $\epsilon = \text{Unity for gaseous medium}$ $v = \frac{h}{b}; \sigma = \frac{b}{c}$		

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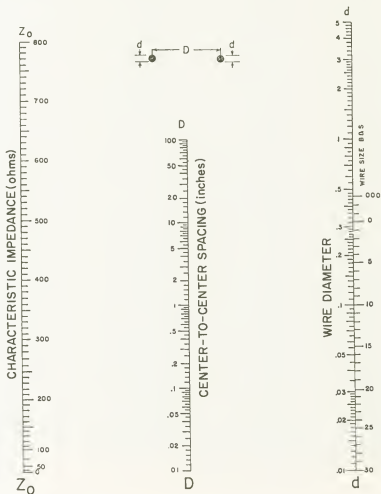
CHARACTERISTIC IMPEDANCE OF BALANCED TWO-WIRE LINES

This nomogram determines the theoretical exact impedance of air-dielectric parallel lines in air or in a vacuum, and remote from any conducting plane. It covers conductors having diameters from 0.01 to 5 in., spaced from 0.01 to 100 in. center-to-center.

$$Z_o = 276 \log_{10} \frac{2D}{d}$$

$$D > 2d$$

FOR EXAMPLE: (1) The impedance of a line using #12 wire spaced 1½ in. is 430 ohms. (2) What is the wire diameter for a 300-ohm line spaced 1¼ in.? Answer: 0.20 in.



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CHARACTERISTICS OF COAXIAL CABLES

▼ START HERE TO SELECT BY TYPE NUMBER

RG CABLE TYPE	INNER CONDUCTOR	PE DI- ELEC- TRIC	SHIELDS	JACKET	ARMOR (.0126 ALUMINUM WIRE)	OPER. VOLTS RMS	LBS. PER M FT.
	MAT. STRAND	O.D.	O.D. INNER OUTER	O.D. MAT. O.D.			
58/U	3C	1 .051 .185	3C	5C .260	NCV .335	—	3000 83
6A/U	CW	1 .0285 .189	3C	C .264	NCV .336	—	2700 74
8/U	C	7 .086 .293	C	—	.340 V .415	—	4000 99
8/AU	C	7 .0285 .293	C	—	.340 NCV .415	—	4000 99
9A/U	3C	7 .086 .285	3C	5C .355	NCV .430	—	4000 126
9B/U	3C	7 .086 .285	3C	5C .355	NCV .430	—	4000 126
10A/U	C	7 .086 .293	C	—	.340 NCV .415	.475	4000 121
11/U	TC	7 .048 .293	C	—	.340 V .415	—	4000 89
11A/U	TC	7 .048 .292	C	—	.340 NCV .412	—	4000 89
12A/U	TC	7 .048 .292	C	—	.340 NCV .412	.475	4000 113
13A/U	TC	7 .048 .290	C	C .355	NCV .430	—	4000 114
14A/U	C	1 .102 .383	C	C .463	NCV .558	—	5500 201
17A/U	C	1 .188 .695	C	—	.760 NCV .885	—	11000 446
18A/U	C	1 .188 .695	C	—	.760 NCV .885	.945	11000 496
19A/U	C	1 .250 .925	C	—	.990 NCV 1.135	—	14000 720
20A/U	C	1 .250 .925	C	—	.990 NCV 1.135	1.195	14000 786
34B/U	C	7 .075 .470	C	—	.535 NCV .640	—	5200 193
35B/U	C	1 .1045 .690	C	—	.760 NCV .880	.945	10000 425
55/U	C	1 .032 .121	TC	TC .176	PE .206	—	1900 31
55A/U	3C	1 .035 .121	3C	5C .176	NCV .216	—	1900 36
55B/U	3C	1 .032 .121	TC	TC .176	PE .206	—	1900 32
58/U	C	1 .032 .121	C	—	.150 V .200	—	1900 24
58A/U	TC	19 .0375 .120	TC	—	.150 V .199	—	1900 25
58C/U	TC	19 .0375 .120	TC	—	.150 NCV .199	—	1900 25
59/U	CW	1 .0253 .150	C	—	.191 V .250	—	2300 36
59B/U	CW	1 .0253 .150	C	—	.191 NCV .246	—	2300 36
62/U	CW	1 .025 .151	C	—	.191 V .250	—	750 34
62A/U	CW	1 .025 .151	C	—	.191 NCV .249	—	750 34
63B/U	CW	1 .0253 .295	C	—	.340 NCV .415	—	1000 78
71/U	CW	1 .025 .151	C	TC .198	PE .239	—	750 42
71A/U	CW	1 .025 .151	TC	TC .198	V .245	—	750 42
71B/U	CW	1 .025 .151	C	TC .208	PE .250	—	750 42
74A/U	C	1 .102 .383	C	C .564	PE .558	.615	5500 230
79B/U	CW	1 .025 .295	C	—	.340 NCV .415	.475	1000 122
164/U	C	1 .1045 .690	C	—	.760 NCV .890	—	10000 392
174/U	CW	7 .019 .060	TC	—	.069 V .105	—	—
177/U	C	1 .195 .690	3C	5C .760	NCV .910	—	14000 465
212/U	3C	1 .056 .189	3C	5C .265	NCV .336	—	3000 85
213/U	C	7 .090 .292	C	—	.340 NCV .412	—	4000 100
214/U	3C	7 .090 .292	3C	5C .360	NCV .432	—	4000 129
215/U	C	7 .090 .292	C	—	.340 NCV .412	—	4000 122
216/U	TC	7 .048 .292	C	C .360	NCV .432	—	4000 115
217/U	C	1 .106 .380	C	C .463	NCV .555	—	5500 202
218/U	C	1 .195 .690	C	—	.760 NCV .880	—	11000 457
219/U	C	1 .195 .690	C	—	.760 NCV .880	.945	11000 507
220/U	C	1 .260 .910	C	—	.990 NCV 1.120	—	14000 725
221/U	C	1 .260 .910	C	—	.990 NCV 1.120	1.195	14000 790
223/U	3C	1 .056 .120	3C	5C .176	NCV .216	—	1900 36
224/U	C	1 .108 .380	C	C .463	NCV .555	.615	5500 232

3C—silver plated copper, C—bare copper, PE—polyethylene, NCV—non-contaminating vinyl,

V—polyvinylchloride, TC—tinned copper, CW—copperweld

▼ START HERE TO SELECT BY CHARACTERISTIC IMPEDANCE

	NOMINAL IMPEDANCE OHMS	CAP. PF. FT.	ATTENUATION (dB/100 FT.) FREQUENCY IN MEGAHERTZ							VP %	RG CABLE TYPE	
			10	50	100	200	400	600	1000			3000
50	^	29.5	.65	1.6	2.4	3.6	5.2	6.6	8.8	16.7	65.9	58/U
75	□	20	.70	1.8	2.9	4.3	6.5	8.3	11.2	22	65.9	6A/U
52	^	29.5	.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	8/U
52	^	29.5	.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	8A/U
52	^	29.5	.45	1.26	2.3	3.4	5.2	6.5	9.0	17	65.9	9A/U
50	^	30	.45	1.26	2.3	3.4	5.2	6.5	9.0	17	65.9	9B/U
52	^	29.5	.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	10A/U
75	□	20.5	.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	11/U
75	□	20.5	.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	11A/U
75	□	20.5	.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	12A/U
74	□	20.5	.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	13A/U
52	^	29.5	.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	14A/U
52	^	29.5	.23	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	17A/U
52	^	29.5	.23	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	18A/U
52	^	29.5	.14	.42	.69	1.1	1.8	2.45	3.5	7.7	65.9	19A/U
52	^	29.5	.14	.42	.69	1.1	1.8	2.45	3.5	7.7	65.9	20A/U
75	□	20	.29	.85	1.3	2.1	3.3	4.5	6.0	12.5	65.9	34B/U
75	□	20.5	.23	.61	.85	1.25	1.95	2.47	3.5	8.6	65.9	35B/U
53.5	^	28.5	1.3	3.2	4.8	7.0	10.5	13.0	17	32	65.9	55/U
50	^	29.5	1.3	3.2	4.8	7.0	10.5	13.0	17	32	65.9	55A/U
53.5	^	28.5	1.3	3.2	4.8	7.0	10.5	13.0	17	32	65.9	55B/U
53.5	^	28.5	1.4	3.5	5.3	8.3	11.5	17.8	20	40	65.9	56/U
50	^	29.5	1.6	4.1	6.2	9.2	14.0	17.5	23.5	45	65.9	58A/U
50	^	29.5	1.6	4.1	6.2	9.2	14.0	17.5	23.5	45	65.9	58C/U
73	□	21	1.1	2.7	4.0	5.7	8.5	10.8	14.0	26	65.9	59/U
75	□	20.5	1.1	2.7	4.0	5.7	8.5	10.8	14.0	26	65.9	59B/U
93	^	13.5	.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	62/U
93	^	13.5	.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	62A/U
125	^	10	.60	1.4	2.0	2.9	4.1	5.1	6.5	11.3	84	63B/U
93	^	13.5	.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	71/U
93	^	13.5	.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	71A/U
93	^	13.5	.82	1.9	2.7	3.9	5.8	7.0	9.0	17	84	71B/U
52	^	29.5	.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	74A/U
125	*	10	.60	1.4	2.0	2.9	4.1	5.1	6.5	11.3	84	79B/U
75	□	20.5	.23	.61	.85	1.25	1.95	2.47	3.5	8.6	65.9	164/U
50	^	30	—	—	—	—	2.0	—	—	—	65.9	174/U
50	^	30	.23	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	177/U
50	^	29.5	.65	1.6	2.4	3.6	5.2	6.6	8.8	16.7	65.9	212/U
50	^	30.5	.56	1.35	2.1	3.1	5.0	6.5	8.8	17.5	65.9	213/U
50	^	30.5	.45	1.26	2.3	3.4	5.2	6.5	9.0	17	65.9	214/U
50	^	30.5	.56	1.35	2.1	3.1	5.0	6.5	8.8	16.7	65.9	215/U
75	□	20.5	.65	1.5	2.15	3.2	4.7	6.0	8.2	18	65.9	216/U
50	^	30	.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	217/U
50	^	30	.225	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	218/U
50	^	30	.225	.60	.95	1.5	2.4	3.2	4.5	9.5	65.9	219/U
50	^	29.5	.17	—	.69	1.12	1.85	—	3.6	7.7	—	220/U
50	^	29.5	.17	—	.69	1.12	1.85	—	3.6	7.7	—	221/U
50	^	30	1.3	3.2	4.8	7.0	10.5	13.0	17.0	37	65.9	223/U
50	^	30	.28	.85	1.5	2.3	3.5	4.4	6.0	11.7	65.9	224/U

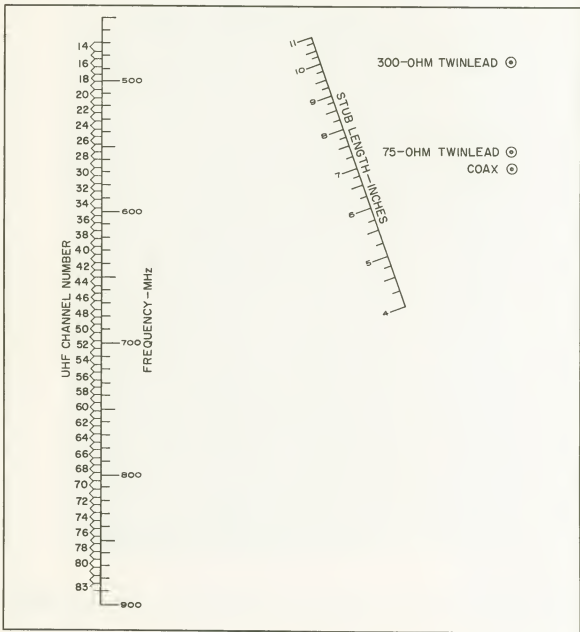
Ohms Code: ^ Through to 55 □ 56 Through 80 * 81 Through 100 * 101 Through 200

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ULTRA-HIGH FREQUENCY HALF-WAVE SHORTING-STUB NOMOGRAM

This nomogram is used to determine the length in inches of shorting stubs required to eliminate interference in the UHF television range.

FOR EXAMPLE: To eliminate an interfering signal at 575 MHz (channel 31) requires a 8½ in. long half-wave shorting stub, if 300-ohm twin lead is used. If 75-ohm twin lead is used, the stub has to be 7¼ in. for the same frequency.



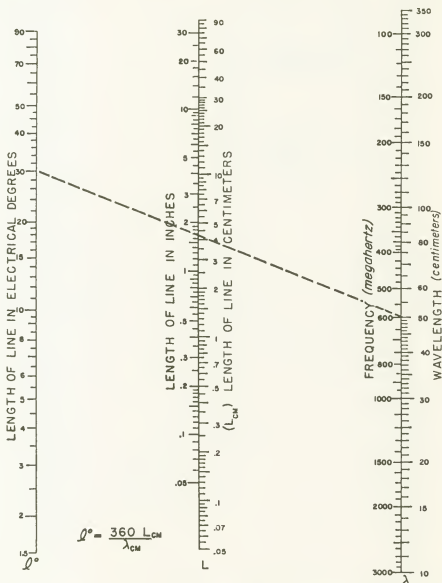
TRANSMISSION LINE NOMOGRAM

This nomogram gives the actual length of line in centimeters and inches when given the length in electrical degrees and the frequency provided that the velocity of propagation on the transmission line is equal to that in free space. The length is equal to that in free space and is given on the L scale intersection by a line between λ on λ° .

FOR EXAMPLE:

$$f = 600 \text{ MHz} \quad \lambda^\circ = 30^\circ$$

$$\text{Length } L = 1.64'' \text{ or } 4.2 \text{ cm}$$

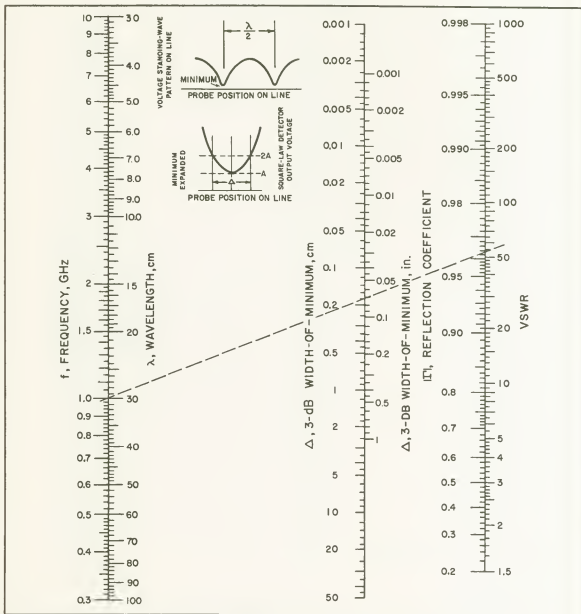


SLOTTED-LINE WIDTH-OF-MINIMUM VSWR NOMOGRAM

This nomogram is used to determine the VSWR and the magnitude of the reflection coefficient by the use of width-of-minimum measurement technique. This technique relies on the fact that there are two comparatively easy-to-find 3-dB points straddling any minimum, as illustrated.

FOR EXAMPLE: A slotted-line width-of-minimum measurement of 0.18 cm, with a 1-GHz source, indicates a VSWR of 53 or a reflection coefficient magnitude of 0.963.

NOTE: The signal-to-noise ratio at the bottom of the minimum must be at least 10 dB for accurate results.

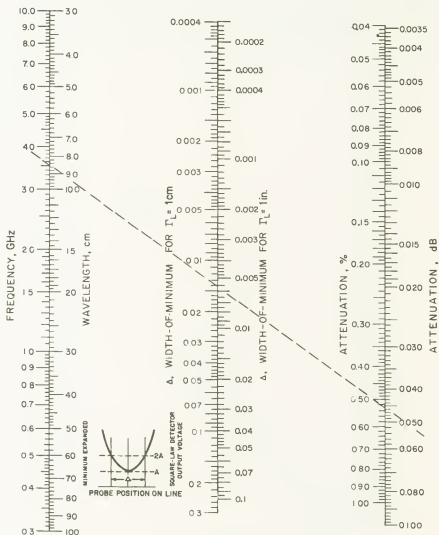


SLOTTED LINE WIDTH-OF-MINIMUM ATTENUATION CALCULATION NOMOGRAM

This nomogram is used to determine the total attenuation between the probe position and the reference plane based on width-of-minimum measurements.

FOR EXAMPLE: With a short circuit termination at the reference plane, if the width-of-the-minimum measured 30 cm from the reference plane is 0.014 cm at 3.5 GHz, then the attenuation is 0.045 dB.

NOTE: The signal-to-noise ratio at the bottom of the minimum should be at least 10 dB for accurate results.



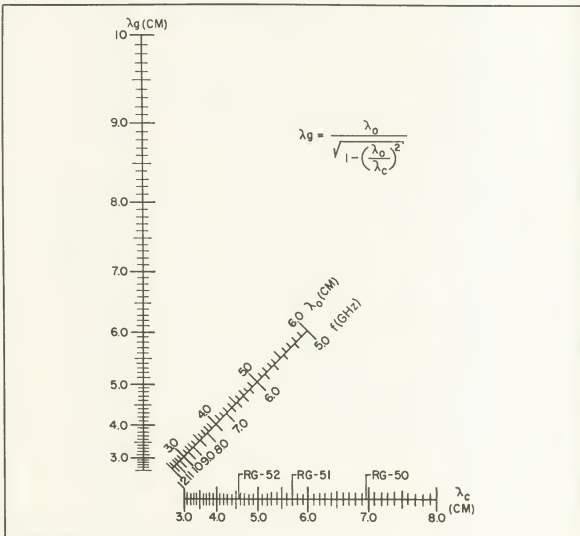
WAVEGUIDE NOMOGRAM

This nomogram relates three significant waveguide characteristics:

waveguide wavelength (λ_g)
 free space wavelength (λ_o) or frequency (f)
 cutoff wavelength (λ_c)

The vertical scale gives waveguide wavelength in centimeters. The horizontal scale is for the cutoff wavelength, and the points corresponding to the cutoff wavelength in the TE_{10} mode of three common waveguides are indicated. The sloping center scale is calibrated in free space wavelength and frequency.

FOR EXAMPLE: (1) The waveguide wavelength at 6 GHz (5 cm free space wavelength) in an RG-50 waveguide is 7.17 cm. (2) Measurement on an RG-51 waveguide shows the waveguide wavelength to be 6.5 cm. The frequency is 7 GHz, which corresponds to a free space wavelength of 4.27 cm.



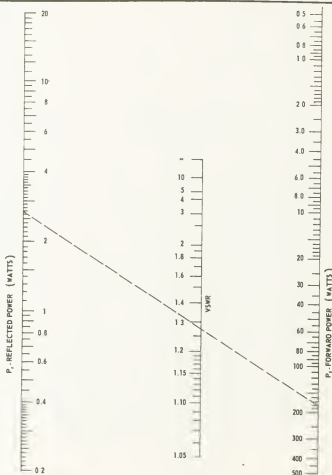
VSWR NOMOGRAM

If a transmission line is not terminated in its characteristic impedance, then some of the energy sent along the line will be reflected back, and standing waves form on the line. The ratio of the maximum to the minimum voltage of the standing waves is the VSWR (voltage standing wave ratio) and indicates the effectiveness of the match between line and load. For a perfectly matched line, the VSWR is 1. The VSWR can be given in a number of ways:

$$VSWR = \frac{Z_L}{Z_0} = \frac{E_{max}}{E_{min}} = \frac{1 + \sqrt{\frac{\text{Reflected power}}{\text{Forward power}}}}{1 - \sqrt{\frac{\text{Reflected power}}{\text{Forward power}}}}$$

This nomogram is based on the last expression and solves for VSWR from measurements of reflected power and forward power.

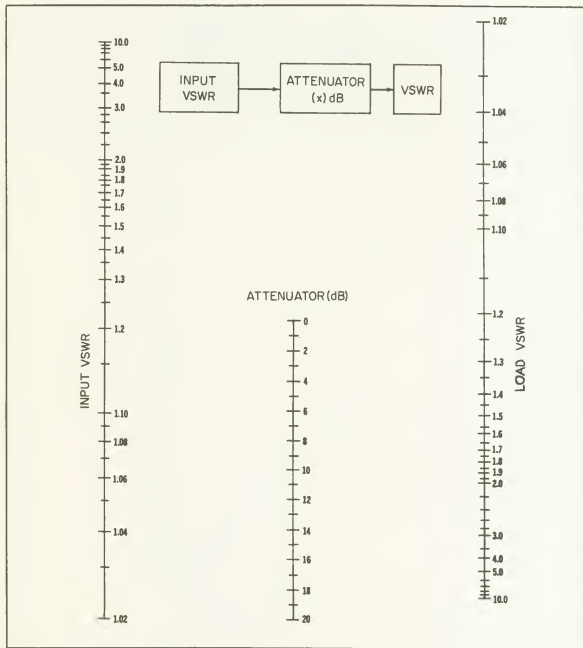
FOR EXAMPLE: For a forward power of 180 W and a reflected power of 2.7 W, the VSWR is 1.27.



VSWR REDUCTION AS A RESULT OF ATTENUATION

This nomogram relates load VSWR, input VSWR, and attenuation. It can be used to find the resultant VSWR with a given amount of attenuation, or to determine the attenuation required for a given VSWR.

FOR EXAMPLE: (1) A 5-dB attenuator will reduce input VSWR to 1.23 if the load VSWR is 2.0. (2) The required attenuation to reduce a load VSWR of 1.8 to an input VSWR of 1.06 is 10.0 dB.



DOPPLER TO SPEED CONVERSION NOMOGRAM

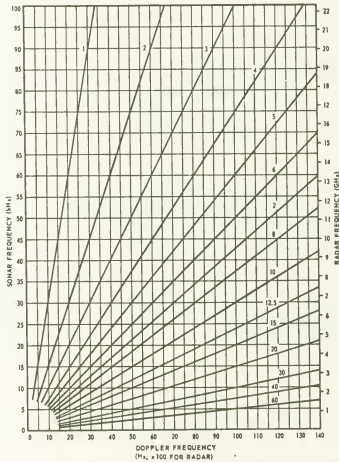
Radar or sonar frequency may be converted to hundreds of miles per hour or knots per hour by using this chart. The base sonar frequency in kHz is given on the left scale and the base radar frequency in GHz is given on the right. Doppler frequency, in Hz for sonar and hundreds of Hz for radar, is shown at the bottom. The diagonals represent target rate of change of range, which is the velocity speed vector in the source's direction.

The basic formula for Doppler speed is:

$$\text{Doppler frequency} = \frac{\text{base f.} \times \text{target range rate}}{\text{signal velocity in medium.}}$$

The signal velocity in medium is 5,000 ft/sec for sonar and 186,000 mi/sec for radar.

FOR EXAMPLE: (1) The base frequency of a sonar system is 40 kHz and its Doppler frequency is 55 Hz. The speed vector is found by the intersection of these two lines on the chart to be approximately 4.1 knots. (2) The base frequency of a radar system is 11 GHz, and the Doppler frequency is 8,000 Hz. The speed vector of the aircraft in miles per hour is found (from the intersection of these two lines) to be approximately 480 mph.



DOPPLER FREQUENCY NOMOGRAM

This nomogram solves for the Doppler frequency, which is produced as a result of relative motion between a transmitter and its receiver or target. The Doppler frequency is a function of transmitted frequency and velocity of motion. The angle to the velocity vector determines the actual relative velocity. For a navigation system (Fig. A) in an airplane, the earth is the target, and the angle A is the acute angle between the aircraft heading and the radar beam. In this case the Doppler shift is downward. A forward-looking radar will produce an upward Doppler shift. For surveillance-type radars (Fig. B), the angle A is the acute angle between the radar beam and target velocity. (Note that the nomogram is based on the Doppler equation for radar and that the Doppler shift for a passive listening device will be half the frequency indicated.)

FOR EXAMPLE: A helicopter navigation system transmits at 10 GHz at an angle of 70° . What is the audio bandwidth required for aircraft velocities of 10 through 200 mph? On the left scales, connect 10 GHz and 10 mph to the tuning scale. From that point on, the tuning scale connecting through 70° gives 100 Hz as the lowest frequency. Repeating the steps using 200 mph in place of 10 mph shows the highest frequency to be 2 kHz. Thus the required bandwidth is 100 to 2,000 Hz. The nomogram is based on the formula

$$f_d = 89.4 \frac{V}{\lambda}$$

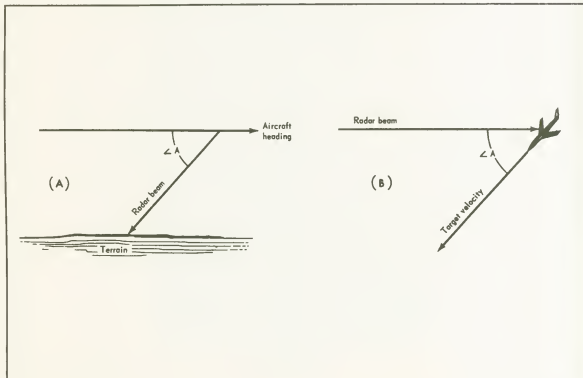
where

f_d = Doppler frequency (Hz)

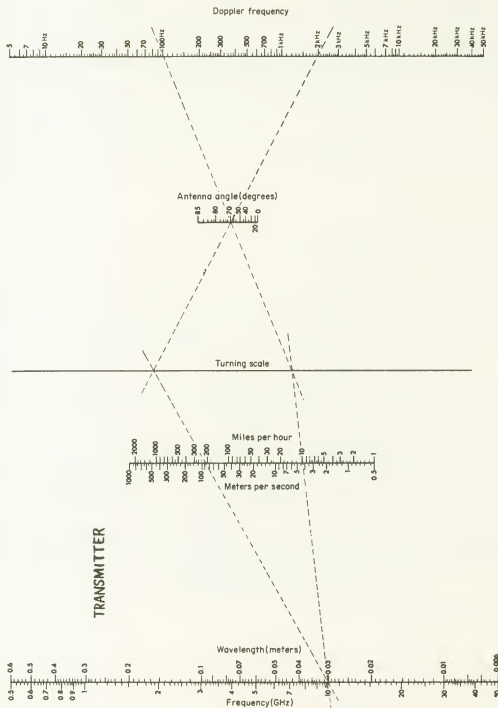
V = velocity in miles per hour

λ = transmitted wavelength in centimeters

Angle-to-velocity vector depends on type of target.



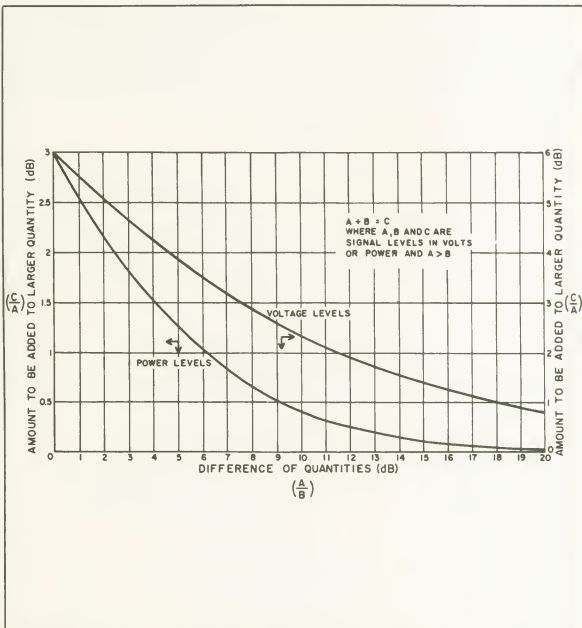
TRANSMITTER



GRAPH FOR ADDING TWO IN-PHASE SIGNALS

This graph determines the combined signal level and shows the number of dB that must be added to the larger signal.

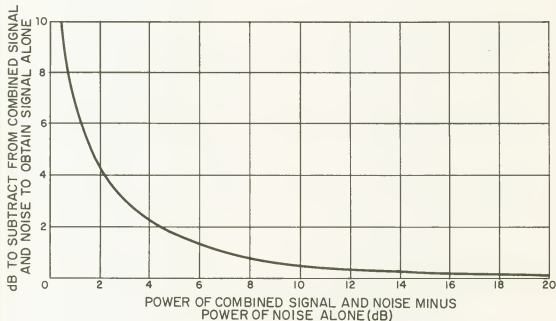
FOR EXAMPLE: Two in-phase signals are -25 dB and -27 dB respectively. The difference is 2 dB and, from the graph, 2.2 dB must be added to the larger signal. Thus, the combined signal power level is -25 dB plus 2.2 dB or -22.8 dB.



GRAPH FOR SEPARATING SIGNAL POWER FROM NOISE POWER

When making transmission loss or crosstalk measurements, the presence of noise is a potential source of error. If the total voltage measured across the load resistance when a signal is being transmitted is 15 dB or more greater than the noise voltage alone, the error in the received voltage measurement will be negligible. If, however, the dB difference between the combined signal and noise voltage and the noise voltage alone is less than 15 dB, a correction must be made. To do so, two voltage measurements must be made. Namely, (1) the noise power in dBm, and (2) the combined noise and signal power in dBm. On the horizontal axis locate the point equal to the difference between the two powers and read on the vertical axis the number of dB to be subtracted from the noise plus signal power and obtain the power of the signal alone.

FOR EXAMPLE: The difference between the measurements of combined noise and crosstalk and noise alone is 5 dB. Thus, 1.7 dB must be subtracted from the combined signal and noise level to obtain the level of the signal alone.



FIELD POWER CONVERSION CHART

Power density is related to field strength by the equation

$$P = \frac{E^2}{120\pi}$$

where

P = the power density

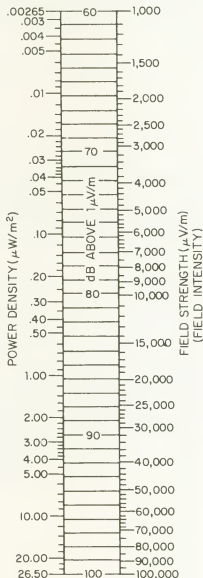
E = the field strength

120π = the resistance of free space

and

This chart converts between field strength and power density.

FOR EXAMPLE: A field strength of 3,000 $\mu\text{V/m}$ corresponds to a power density of 0.024 $\mu\text{W/m}^2$ and is 70.5 dB above 1 $\mu\text{V-m}$.



Q SIGNALS (MNEMONIC CODE)

The Q code was first adopted in 1912 by international treaty agreement to overcome the language barriers faced by ship operators of all nations as they tried to communicate with shore stations all over the world. Many of the original list of 50 signals are still in use with their definitions unchanged. Many more have been added from time to time, and the official meanings of some signals have been changed. In addition, many signals have been informally adopted for use by amateurs in situations not covered by the official lists.

The list below includes virtually every Q signal which could, even remotely, be thought to have an application in amateur radio communication. To simplify the task of finding the definition of an unfamiliar signal, we have combined all the signals into a single alphabetical list, mixing "official" and unofficial signals. The definitions listed are, in most cases, the official ones, taken verbatim from the treaty. In other cases, where definitions are not the official ones, they are as amateurs universally understand them, for purposes of amateur communications. The QN signals, adopted by ARRL for traffic net use, have official definitions which refer to aeronautical situations.

QAM	What is the latest available meteorological observation for (place)? The observation made at (time) was . . .	Transmit (1—test tape, 2—test sentence) by RTTY.
QAP	Shall I listen for you (or for . . .) on . . . kHz? Listen for me (or for . . .) on . . . kHz.	QJI Shall I transmit continuous (1—mark, 2—space) RTTY signal? Transmit continuous (1—mark, 2—space) signal.
QAR	May I stop listening on the watch frequency for . . . minutes? You may stop listening on the watch frequency for . . . minutes?	QJK Are you receiving continuous (1—mark, 2—space, 3—mark bias, 4—space bias)? I am receiving continuous (1—mark, 2—space, 3—mark bias, 4—space bias).
QBF	Have we worked before in this contest? We have worked before in this contest.	QKF May I be relieved at . . . hours? You may expect to be relieved at . . . hours by . . .
QHM	I will tune from the high end of the band toward the middle (Used after a call or CQ.)	QLM I will tune for answers from the low end of the band toward the middle.
QIF	What frequency is . . . using? He is using . . . kHz.	QMD I will tune for answers from my frequency down.
QJA	Is my RTTY (1—tape, 2—M/S) reversed? It is reversed.	QMH I will tune for answers from the middle of the band toward the high end.
QJB	Shall I use (1—TTY, 2—reperf)? (For RTTY use.) Use (1—TTY, 2—reperf)	QML I will tune for answers from the middle of the band toward the low end.
QJC	Check your RTTY (1—TC, 2—auto head, 3—reperf, 5—Printer, 7—keyboard).	QMU I will tune for answers from my frequency upward.
QJD	Shall I transmit (1—letters, 2—figs)? (For RTTY) Transmit (1—letters, 2—figs).	QMT Will you mail the traffic? I will accept the traffic for delivery by mail.
QJE	Shall I send (1—wide, 2—narrow, 3—correct) RTTY shift? Your RTTY shift is (1—wide, 2—narrow, 3—correct).	QNA* Answer in prearranged order.
QJF	Does my RTTY signal check out OK? Your RTTY signal checks out OK.	QNB* Act as relay between . . . and . . .
QJH	Shall I transmit (1—test tape, 2—test sentence) by RTTY?	QNC All net stations copy. I have a message for all net stations.
		QND* Net is directed (controlled by net control station).
		QNE* Entire net stand by.
		QNF Net is free (not controlled).
		QNG Take over as net control station.
		QNH Your net frequency is high.
		QNI * Net stations report in.*

*For use only by Net Control Station

	I am reporting into the net. (Follow with list of traffic or QRU.)		Your exact frequency (or that of...) is ... kHz (or MHz).
QNJ	Can you copy me?	QRH	Does my frequency vary?
	Can you copy ...?		Your frequency varies.
QNK*	Transmit messages for ... to ...	QRI	How is the tone of my transmission?
QNL	Your net frequency is low.		The tone of your transmission is (1—good, 2—variable, 3—bad.
QNM*	You are QRMing the net. Stand by.	QRJ	Are you receiving me badly? Are my signals weak?
QNN	Net control station is ...*		I am receiving you badly. Your signals are too weak.
	What station has net control?	QRK	What is the intelligibility of my signals (or those of...)?
QNQ	Station is leaving the net.		The intelligibility of your signals (or those of...) is 1—bad, 2—poor, 3—fair, 4—good, 5—excellent.
QNP	Unable to copy you.	QRL	Are you busy?
	Unable to copy ...		I am busy (or I am busy with...). Please do not interfere.
QNQ*	QSY to ... and wait for ... to finish. Then send him traffic for ...	QRM	Are you being interfered with?
QNR*	Answer ... and receive traffic.		I am being interfered with (1—nil, 2—slightly, 3—moderately, 4—severely, 5—extremely).
QNS	Following stations are in the net.* (Follow with list.) Request list of stations in the net.	QRN	Are you troubled by static?
QNT	I request permission to leave the net for ... minutes.		I am troubled by static (1—nil, 2—slightly, 3—moderately, 4—severely, 5—extremely).
QNU*	The net has traffic for you. Stand by.	QRQ	Shall I increase transmitter power?
QNV	Establish contact with ... on this freq. If successful QSY to ... and send traffic for ...		Increase transmitter power.
QNW	How do I route messages for ...?	QRP	Shall I decrease transmitter power?
QNX	You are excused from the net.*		Decrease transmitter power.
	Request to be excused from the net.	QRQ	Shall I send faster?
QNY*	Shift to another frequency (or to ... kHz) to clear traffic with ...		Send faster (... words per minute).
QNZ*	Zero beat your signal with mine.	QRR	Are you ready for automatic operation?
QRA	What is the name of your station?		I am ready for automatic operation. Send at ... words per minute.
	The name of my station is ...	QRRR	Distress call signal for use by amateur c.w. and RTTY stations. To be used only in situations where there is danger to human life or safety.
QRB	How far approximately are you from my station?	QRS	Shall I send more slowly?
	The approximate distance between our station is ... nautical miles (or kilometers).		Send more slowly.
QRD	Where are you bound for and where are you from?	QRT	Shall I stop sending?
	I am bound for ... from ...		Stop sending.
QRE	What is your estimated time of arrival at ... (or over ...) (place)?	QRU	Have you anything for me?
	My estimated time of arrival at ... (or over ...) (place) is ... hours.		I have nothing for you.
QRF	Are you returning to ... (place)?	QRV	Are you ready?
	I am returning to ... (place).		I am ready.
	or	QRW	Shall I inform ... that you are calling him on ... kHz?
	Return to ... (place).		
QRG	Will you tell me my exact frequency (or that of...)?		

*For use only by Net Control Station.

	Please inform ... that I am calling him on ... kHz.		I can communicate with ... direct (or by relay through ...).
QRX	When will you call me again? I will call you again at ... hours (on ... kHz).	QSP	Will you relay to ... free of charge? I will relay to ... free of charge.
QRY	What is my turn? (Relates to communication) Your turn is Number ... (or according to any other indication). (Relates to communication)	QSQ	Have you a doctor on board [or is ... (name of person) on board] ? I have a doctor on board [or ... (name of person) is on board].
QRZ	Who is calling me? You are being called by ... (on ... kHz).	QSR	Shall I repeat the call on the calling frequency? Repeat your call on the calling frequency; did not hear you (or have interference).
QSA	What is the strength of my signals (or those of ...)? The strength of your signals (or those of ...) is (1—scarcely perceptible, 2—weak, 3—fairly good, 4—good, 5—very good).	QSS	What working frequency will you use? I will use the working frequency ... kHz.
QSB	Are my signals fading? Your signals are fading.	QST	Calling all radio amateurs.
QSD	Is my keying defective? Your keying is defective.	QSU	Shall I send or reply on this frequency (or on ... kHz)? Send or reply on this frequency (or on ... kHz).
QSG	Shall I send ... messages at a time? Send ... messages at a time.	QSV	Shall I send a series of V's on this frequency (or ... kHz)? Send a series of V's on this frequency (or ... kHz).
QSH	Are you able to home on your D/F equipment? I am able to home on my D/F equipment (on station ...).	QSW	Will you send on this frequency (or on ... kHz)? I am going to send on this frequency (or on ... kHz).
QSI	I have been unable to break in on your transmission. or Will you inform ... (call sign) that I have been unable to break in on his transmission (on ... kHz).	QSX	Will you listen to ... (call sign(s)) on ... kHz? I am listening to ... (call sign(s)) on ... kHz.
QSK	Can you hear me between your signals and if so can I break in on your transmission? I can hear you between my signals; break in on my transmission.	QSY	Shall I change to transmission on another frequency? Change to transmission on another frequency (or on ... kHz).
QSL	Can you acknowledge receipt? I am acknowledging receipt.	QSZ	Shall I send each word or group more than once? Send each word or group twice (or ... times).
QSM	Shall I repeat the last telegram which I sent you (or some previous telegram)? Repeat the last telegram which you sent me (or telegram(s) number(s) ...).	QTA	Shall I cancel message number ... ? Cancel message number ...
QSN	Did you hear me [or ... (call sign)] on ... kHz? I did hear you [or ... (call sign)] on ... kHz.	QTB	Do you agree with my counting of words? I do not agree with your counting of words; I will repeat the first letter or digit of each word or group.
QSO	Can you communicate with ... direct (or by relay)?	QTC	How many messages have you to send? I have ... messages for you (or for ...).
		QTG	Will you send two dashes of ten seconds each followed by your call sign (re-

	peated ... times) (on ... kHz)? or Will you request ... to send two dashes of ten seconds followed by his call sign (repeated ... times) on ... kHz?		
	I am going to send two dashes of ten seconds each followed by my call sign (repeated ... times) (on ... kHz). or I have requested ... to send two dashes of ten seconds followed by his call sign (repeated ... times) on ... kHz.		
QTH	What is your position in latitude and longitude (or according to any other indication)?		
	My position is ... latitude ... longitude (or according to any other indication).		
QTN	At what time did you depart from ... (place)?		
	I departed from ... (place) at ... hours.		
QTO	Have you left dock (or port)? or Are you airborne?		
	I have left dock (or port). or I am airborne.		
QTP	Are you going to enter dock (or port)? or Are you going to alight (or land)?		
	I am going to enter dock (or port). or I am going to alight (or land).		
QTO	Can you communicate with my station by means of the International Code of Signals?		
	I am going to communicate with your station by means of the International Code of Signals.		
QTR	What is the correct time?		
	The correct time is ... hours.		
QTS	Will you send your call sign for tuning purposes or so that your frequency can be measured now (or at ... hours) on ... kHz?		
	I will send my call sign for tuning purposes or so that my frequency may be measured now (or at ... hours) on ... kHz.		
QTU	What are the hours during which your station is open?		
	My station is open from ... to ... hours.		
QTV	Shall I stand guard for you on the frequency of ... kHz (from ... to ... hours)? Stand guard for me on the frequency of ... kHz (from ... to ... hours).		
QTX	Will you keep your station open for further communication with me until further notice (or until ... hours)?		
	I will keep my station open for further communication with you until further notice (or until ... hours).		
QTY	Are you proceeding to the position of incident and if so when do you expect to arrive?		
	I am proceeding to the position of incident and expect to arrive at ... hours on ... (date).		
QTY	Are you continuing the search?		
	I am continuing the search for ... (aircraft, ship, survival craft, survivors, or wreckage).		
QUA	Have you news of ... (call sign)?		
	Here is news of ... (call sign).		
QUB	Can you give me in the following order information concerning: the direction in degrees TRUE and speed of the surface wind; visibility; present weather; and amount, type, and height of base of cloud above surface elevation at ... (place of observation)?		
	Here is the information requested: ... (The units used for speed and distances should be indicated.)		
QUC	What is the number (or other indication) of the last message you received from me [or from ... (call sign)]?		
	The number (or other indication) of the last message I received from you [or from ... (call sign)] is ...		
QUE	Can you use telephony in ... (language), with interpreter if necessary; if so, on what frequencies?		
	I can use telephony in ... (language) on ... kHz.		
QUF	Have you received the distress signal sent by ... (call sign of station)?		
	I have received the distress signal sent by ... (call sign of station) at ... hours.		
QUH	Will you give me the present barometric pressure at sea level?		
	The present barometric pressure at sea level is ... (units).		
QUK	Can you tell me the condition of the sea observed at ... (place or coordinates)?		
	The sea at ... (place or coordinates) is ...		
QUM	May I resume normal working?		
	Normal working may be resumed.		

RADIO TELEPHONE CODE

General Station Operation

- 10-1 Receiving poorly.
- 10-2 Signals good.
- 10-3 Stop transmitting.
- 10-4 Okay—Affirmative—Acknowledged.
- 10-5 Relay this message.
- 10-6 Busy, stand by.
- 10-7 Leaving the air.
- 10-8 Back on the air and standing by.
- 10-9 Repeat message.
- 10-10 Transmission completed, standing by.
- 10-11 Speak slower.
- 10-13 Advise weather and road conditions.
- 10-18 Complete assignment as quickly as possible.
- 10-19 Return to base.
- 10-20 What is your location? My location is . . .
- 10-21 Call . . . by telephone.
- 10-22 Report in person to . . .
- 10-23 Stand by.
- 10-24 Have you finished? I have finished.
- 10-25 Do you have contact with . . . ?

Emergency or Unusual

- 10-30 Does not conform to Rules and Regulations.
- 10-33 Emergency traffic this station.
- 10-35 Confidential information.
- 10-36 Correct time.
- 10-41 Tune to channel . . . for test, operation, or emergency service.
- 10-42 Out of service at home.
- 10-45 Call . . . by phone.
- 10-54 Accident.
- 10-55 Wrecker or tow truck needed.
- 10-56 Ambulance needed.

Net Message Handling

- 10-60 What is next message number?
- 10-62 Unable to copy, use CW.
- 10-63 Net clear.
- 10-64 Net is clear.
- 10-66 Cancellation.
- 10-68 Repeat dispatch on message.
- 10-69 Have you dispatched message . . . ?
- 10-70 Net message.
- 10-71 Proceed with transmission in sequence.

Personal

- 10-82 Reserve room for . . .
- 10-84 What is your telephone number?
- 10-88 Advise present phone number of . . .

Technical

- 10-89 Repairman needed.
- 10-90 Repairman will arrive at your station . . .
- 10-92 Poor signal, have transmitter checked.
- 10-93 Frequency check.
- 10-94 Give a test without voice for frequency check.
- 10-95 Test with no modulation.
- 10-99 Unable to receive your signals.

INTERNATIONAL MORSE CODE

Alphabetical

A * —	J * — — —	S * * *
B — * * *	K — * —	T —
C — * — *	L * — * *	U * — —
D — * *	M — —	V * * * —
E *	N * —	W * — —
F * * — *	O — — —	X — * * —
G — — *	P * — * *	Y * — * —
H * * * *	Q — * — *	Z — — * *
I * *	R * — *	

By Groups

Group One	Group Two	Group Three
E *	A * —	R * — *
I * *	W * — —	F * * * *
S * * *	J * — — —	L * — * *
H * * * *	N * —	U * —
T —	D * — *	V * * * —
M — —	B * — * *	
O — — —		
Group Four		
K * — *	Q — * * —	
X * — * —	G * — * *	
C * — * *	Z * — * *	
Y * — * —	P * — * *	

Numerals and Punctuation

1 * — — — —	6 * * * * *
2 * * — — —	7 — — * * *
3 * * * — —	8 — — — * *
4 * * * —	9 — — — — *
5 * * * * *	0 — — — — —
Period * — * — *	
Comma — * — — —	
Question mark * * — — * *	
Error * * * * * *	
Double dash * — * — *	
Fraction bar — * * * *	
Wait * — * * *	
Invitation to transmit — * —	
End of message (AR) * — * — *	
End of transmission * * * — * —	

Special Foreign Letters

Å (German) * — * —
Ä or A (Spanish-Scandinavian) * — * —
CH (German-Spanish) — — — —
E (French) * * — *
Ñ (Spanish) — — * — —
Ö (German) — — * —
Ü (German) * * — —

SIGNAL REPORTING CODES

RST Code

The standard amateur method of giving signal strength reports. For phone operation only the first two sets of numbers are used with the words "readability" and "strength."

Readability (R)

1. Unreadable
2. Barely readable, occasional words distinguishable
3. Readable with considerable difficulty
4. Readable with practically no difficulty
5. Perfectly readable

Signal Strength (S)

1. Faint; signal barely perceptible
2. Very weak signal
3. Weak signal
4. Fair signal
5. Fairly good signal
6. Good signal
7. Moderately strong signal
8. Strong signal
9. Extremely strong signal

Tone (T)

1. Extremely rough, hissing signal
2. Very rough ac signal
3. Rough, low-pitched ac signal
4. Rather rough ac signal
5. Musically modulated signal
6. Modulated signal, slight whistle
7. Near dc signal, smooth ripple
8. Good dc signal, trace of ripple
9. Purest dc signal

If the signal has the steadiness of crystal control, add "X" after the RST report; add "C" for a chirp; and "K" for a keying click.

A typical report might be: "RST579X," meaning "Your signals are perfectly readable, moderately strong, have a perfectly clear tone, and have the stability of a crystal-controlled transmitter."

This reporting system is used on both CW and voice, leaving out the "Tone" report on voice.

SINPO Code

A reporting method used in the shortwave field. All the numbers after the letters range from one to five. Q-code equivalents for each characteristic are also shown.

FOR EXAMPLE: A typical report for a station that is coming in loud and clear would read: SINPO 55555.

<i>S</i> Signal Strength (QSA)	<i>I</i> Interference (QRM)	<i>N</i> Atmospheric Noise (QRN)	<i>P</i> Propagation Disturbance (QSB)	<i>O</i> Overall Merit (QRK)
5 Excellent	5 None	5 None	5 None	5 Excellent
4 Good	4 Slight	4 Slight	4 Slight	4 Good
3 Fair	3 Moderate	3 Moderate	3 Moderate	3 Fair
2 Poor	2 Severe	2 Severe	2 Severe	2 Poor
1 Barely audible	1 Extreme	1 Extreme	1 Extreme	1 Unusable

555 Code

Another reporting code sometimes used in the shortwave field.

<i>Signal Strength</i>	<i>Interference</i>	<i>Overall Merit</i>
0 Inaudible	0 Total	0 Unusable
1 Poor	1 Very severe	1 Poor
2 Fair	2 Severe	2 Fair
3 Good	3 Moderate	3 Good
4 Very good	4 Slight	4 Very good
5 Excellent	5 None	5 Excellent

SINPFEMO Code

This eight-figure signal reporting method rates eight characteristics of a signal. (If a characteristic is not rated, the letter "x" is used instead of a numeral.)

Rating Scale	<i>S</i>	<i>I</i>	<i>N</i>	<i>P</i>	<i>F</i>	<i>E</i>	<i>M</i>	<i>O</i>
	Signal Strength	Degrading Effect of			Frequency of Fading	Modulation		Overall Rating
		Interference (QRM)	Noise (QRN)	Propagation Disturbance		Quality	Depth	
5	Excellent	Nil	Nil	Nil	Nil	Excellent	Maximum	Excellent
4	Good	Slight	Slight	Slight	Slow	Good	Good	Good
3	Fair	Moderate	Moderate	Moderate	Moderate	Fair	Fair	Fair
2	Poor	Severe	Severe	Severe	Fast	Poor	Poor or nil	Poor
1	Barely audible	Extreme	Extreme	Extreme	Very fast	Very poor	Continuously overmodulated	Unusable

COMMERCIAL RADIO OPERATOR AND AMATEUR OPERATOR LICENSES REQUIREMENTS

Amateur Operator Licenses

<i>Class</i>	<i>Prior Experience</i>	<i>Code Test</i>	<i>Written Examination</i>	<i>Privileges</i>	<i>Term</i>
Novice	None	5 w.p.m.	Elementary theory and regulations	Al Telegraphy in 3.7-3.75, 7.1-7.15, 21.1-21.2, 28.1-28.2 MHz. 250 watts maximum input.	5 years, renewable
Technician	None	5 w.p.m. (Credit given to Novice Class Licensees)	General theory and regulations	All amateur privileges above 50 MHz. Also novice privileges.	5 years, renewable
General	None	13 w.p.m.	General theory and regulations (Credit given to Technician Class Licensees)	1.8-2, ^a 3.525-3.775, 3.89-4, 7.025-7.15, 7.225-7.3, 14.025-14.2, 14.275-14.35, 21.025-21.25, 21.35-21.45, 28.0-29.7 MHz, and all amateur privileges above 50 MHz.	5 years, renewable
Advanced	None	13 w.p.m. (Credit is given to General Class Licensees)	Intermediate theory and regulations	1.8-2, ^a 3.525-3.775, 3.8-4, 7.025-7.3, 14.025-14.45, 21.025-21.25, and all amateur frequencies above 21.27 MHz.	5 years, renewable
Amateur Extra	None	20 w.p.m.	Advanced theory and regulations	All amateur privileges	5 years, renewable

^aThe 1.8-2 band frequency and power assignments differ from state to state. Check with nearest FCC office.

Commercial Radio Operator Licenses

<i>Type of License</i>	<i>Age Minimum</i>	<i>Code Requirement</i>	<i>Written Test</i>	<i>Term of License</i>
Restricted Radiotelephone Permit	14 years	None	None; obtained by declaration (FCC Form 753)	Lifetime
Marine Radio Operator Permit	None	None	Elements 1, 2	5 years, renewable
General Radiotelephone License	None	None	Element 3	5 years, renewable
Third Class Radiotelegraph Permit	None	16 code groups 20 plain words per minute	Elements 1, 2, 5	5 years renewable
Second Class Radiotelegraph License	None	16 code groups 20 plain words per minute	Elements 1, 2, 5, 6	5 years, renewable
First Class Radiotelegraph License	21 years; one year experience	20 code groups, 25 plain words per minute	Elements 1, 2, 5, 6	5 years, renewable

Commercial Examination Elements

NO. 1, BASIC LAW-

Provisions of laws, treaties and regulations with which every marine operator should be familiar. (20 Questions, multiple choice type)

NO. 2, BASIC OPERATING PRACTICE-

Operating procedures and practices generally followed or required in communicating by marine radio-telephone stations. (20 Questions, multiple choice type)

NO. 3, BASIC RADIOTELEPHONE-

Technical, legal and other matters including basic operating practices and provisions of laws, treaties and regulations applicable to operating radiotelephone stations other than broadcast. (100 Questions, multiple choice type)

NO. 5, RADIOTELEGRAPH OPERATING PRACTICE-

Radio operating procedures and practices generally followed or required in communicating by radiotelegraph stations primarily other than in the maritime mobile services of public correspondence. (50 Questions, multiple choice type)

NO. 6, ADVANCED RADIOTELEGRAPH-

Technical, legal matters applicable to operating all classes of radiotelegraph stations including maritime mobile services of public correspondence, message traffic routing and accounting, radio navigational aids, etc. (100 Questions)

NO. 7, AIRCRAFT RADIOTELEGRAPH-

Special endorsement on Radiotelegraph First and Second Class Operator Licenses. Theory and practice in operation of radio communication and navigational systems in use on aircraft. (100 Questions, multiple choice type; code test of 20 code groups per minute and 25 WPM plain language.)

NO. 8, SHIP RADAR TECHNIQUES-

Special endorsement on Radiotelegraph or Radiotelephone First or Second Class Operator Licenses. Specialized theory and practice applicable to proper installation, servicing and maintenance of ship radar equipment in use for marine navigational purposes. (50 Questions, multiple choice type)

INTERNATIONAL PHONETIC ALPHABET

To avoid errors or misunderstanding during voice communication, the new international phonetic alphabet has been adopted.

Letter	Name	Pronunciation	Letter	Name	Pronunciation
A	Alfa	AL-fah	N	November	No-VEM-ber
B	Bravo	BRAH-voh	O	Oscar	OSS-cah
C	Charlie	CHAR-lee (or SHAR-lee)	P	Papa	Pah-PAH
D	Delta	DELL-tah	Q	Quebec	Keh-BECK
E	Echo	ECK-oh	R	Romeo	ROW-me-oh
F	Foxtrot	FOKS-trot	S	Sierra	See-ALR-rah
G	Golf	GOLF	T	Tango	TANG-go
H	Hotel	HOH-tel	U	Uniform	YOU-nee-form (or OO-nee-form)
I	India	IN-dee-ah	V	Victor	VIK-tah
J	Juliett	JEW-lee-ett	W	Whiskey	WISS-key
K	Kilo	KEY-loh	X	X-ray	ECKS-ray
L	Lima	LEE-mah	Y	Yankee	YANG-key
M	Mike	MIKE	Z	Zulu	ZOO-loo

ARRL (AMERICAN RADIO RELAY LEAGUE) WORD LIST FOR VOICE COMMUNICATION

A—Adam	N—Nancy
B—Baker	O—Otto
C—Charlie	P—Peter
D—David	Q—Queen
E—Edward	R—Robert
F—Frank	S—Susan
G—George	T—Thomas
H—Henry	U—Union
I—Ida	V—Victor
J—John	W—William
K—King	X—X-Ray
L—Lewis	Y—Young
M—Mary	Z—Zebra

Example: W1AW . . . W1
ADAM WILLIAM . . . W1AW

TRANSMISSION TRAVEL TIME

The time required for electromagnetic energy to travel interplanetary distances is significant. Shown here are some typical times and distances related to the earth's position.

Moon	(overhead)	=	23.9×10^4 n mi	1.27 sec one way
Venus	(nearest)	=	22.4×10^6 n mi	139.00 sec one way
	(farthest)	=	139.0×10^6 n mi	859.00 sec one way
Mars	(nearest)	=	42.4×10^6 n mi	262.00 sec one way
	(farthest)	=	203.9×10^6 n mi	1259.00 sec one way
Jupiter	(nearest)	=	339.8×10^6 n mi	2099.00 sec one way
	(farthest)	=	501.2×10^6 n mi	3096.00 sec one way

CLASSIFICATION OF EMISSIONS

In accordance with Federal Communications Commission Rules and Regulations 2.201, Subpart C, the following system of designating emission, modulation, and transmission characteristics is employed.

(a) Emissions are designated according to their classification and their necessary bandwidth.

(b) Emissions are classified and symbolized according to the following characteristics.

(1) Type of modulation of main carrier.

(2) Type of transmission.

(3) Supplementary characteristics.

(c) Types of modulation of main carrier:

(1) Amplitude A
(2) Frequency (or Phase) F
(3) Pulse P

(d) Types of transmission:

(1) Absence of any modulation intended to carry information 0
(2) Telegraphy without the use of a modulating audio frequency 1

(3) Telegraphy by the on-off keying of a modulating audio frequency or audio frequencies, or by the on-off keying of the modulated emission (special case: an unkeyed modulated emission) 2

(4) Telephony (including sound broadcasting) 3
(5) Facsimile (with modulation of main carrier either directly or by a frequency modulated sub-carrier) 4
(6) Television (visual only) 5
(7) Four-frequency duplex telegraphy 6
(8) Multichannel voice-frequency telegraphy 7
(9) Cases not covered by the above 9

(e) Supplementary characteristics:

(1) Double sideband (None)
(2) Single sideband:
(i) Reduced carrier A
(ii) Full carrier H
(iii) Suppressed carrier J
(3) Two independent sidebands B
(4) Vestigial sideband C
(5) Pulse:
(i) Amplitude modulated D
(ii) Width (or duration) modulated E
(iii) Phase (or position) modulated G
(iv) Code modulated G

(f) The classification of typical emissions is tabulated as follows:

Type of modulation of main carrier	Type of transmission	Supplementary characteristics	Symbol
Amplitude modulation.....	With no modulation.....	.....	A0
	Telegraphy without the use of a modulating audio frequency (by on-off keying).....	.....	A1
	Telegraphy by the on-off keying of an amplitude modulating audio frequency or audio frequencies, or by the on-off keying of the modulated emission (special case: an unkeyed emission amplitude modulated).....	.....	A2
	Telephony.....	Double sideband.....	A3
		Single sideband, reduced carrier.....	A3A
		Single sideband, suppressed carrier.....	A3J
		Two independent sidebands.....	A3B
		.....	A4
	Facsimile (with modulation of main carrier either directly or by a frequency modulated sub-carrier).....	Single sideband, reduced carrier.....	A4A
	Facsimile.....	Vestigial sideband.....	A4C
	Television.....	Single sideband, reduced carrier.....	A7A
	Multichannel voice-frequency telegraphy.....	Two independent sidebands.....	A7B
	Cases not covered by the above, e.g., a combination of telephony and telegraphy.....	.....
Frequency (or Phase) modulation.....	Telegraphy by frequency shift keying without the use of a modulating audio frequency or of two frequencies being emitted at any instant.....	.....	F1
	Telegraphy by the on-off keying of a frequency modulating audio frequency or by the on-off keying of a frequency modulated emission (special case: an unkeyed emission, frequency modulated).....	.....	F2
	Telephony.....	.....	F3
	Facsimile by direct frequency modulation of the carrier.....	.....	F4
	Television.....	.....	F4
	Four-frequency duplex telegraphy.....	.....	F6
	Cases not covered by the above, in which the main carrier is frequency modulated.....	.....	F9
Pulse modulation.....	A pulsed carrier without any modulation intended to carry information (e.g., radar).....	.....	P0
	Telegraphy by the on-off keying of a pulsed carrier without the use of a modulating audio frequency.....	.....	P1D
	Telegraphy by the on-off keying of a modulating audio frequency or audio frequencies, or by the on-off keying of a modulated pulsed carrier (special case: an unkeyed modulated pulsed carrier).....	.....
	Telephony.....	Audio frequency or audio frequencies modulating the amplitude of the pulses.....	P2D
		Audio frequency or audio frequencies modulating the width (or duration) of the pulses.....	P2E
		Audio frequency or audio frequencies modulating the phase (or position) of the pulses.....	P2F
		Amplitude modulated pulses.....	P2D
		Width (or duration) modulated pulses.....	P2E
		Phase (or position) modulated pulses.....	P2F
		Code modulated pulses (after sampling and quantization).....	P2G
	Cases not covered by the above in which the main carrier is pulse modulated.....	.....	P9

Class	Name	Code	Action of Modulating Signal
A	Pulse-time modulation	PTM	Varies some characteristic of pulse with respect to time.
	Pulse-position modulation	PPM	Varies position (phase) of pulse on time base.
	Pulse-duration modulation	PDM	Varies width of pulse (also called PWM, or Pulse-Width Modulation).
	Pulse-shape modulation		Varies shape of pulse.
	Pulse-frequency modulation	PFM	Varies pulse recurrence frequency.
B	Pulse-amplitude modulation	PAM	Varies amplitude of pulse—consists of two types: one using unipolar pulses, the other using bipolar pulses.
C	Pulse-code modulation	PCM	Varies the makeup of a series of pulses and spaces. Individual systems are classified as follows: <u>Binary</u> -pulse and spaces, or positive and negative pulses. <u>Ternary</u> -positive pulses, negative pulses, and spaces. <u>N-ary</u> -more complex combinations of pulses and spaces.

MICROPHONE OUTPUT NOMOGRAM

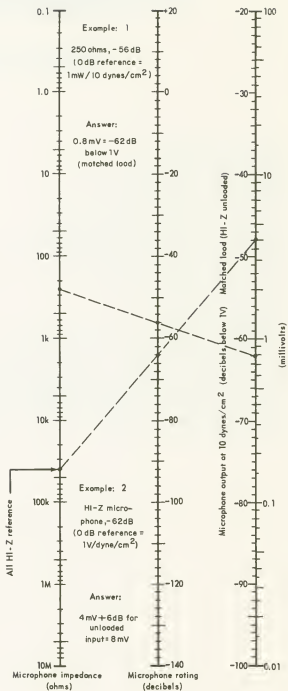
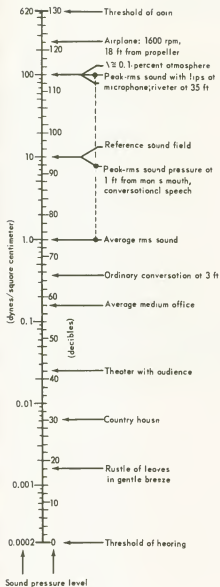
This nomogram determines the output voltages for various microphone ratings and relates this output to actual sound pressure levels.

Two methods of specifying microphone levels are in general use. Acoustic input and electrical output are specified so that the microphone can be considered as a generator, with sound pressure input and voltage or power output.

For low-impedance microphones, output is given in decibels referenced to 1 mW for 10 dynes/cm² sound pressure. For high-impedance microphones, output is given in decibels referenced to 1 V for 1 dyne/cm² sound pressure. (In both, output is into a resistive load equal to the impedance of the microphone.)

This nomogram is prepared for microphone preamplifiers with low input impedances matched to the microphone impedance. (Open-circuit voltage is 6 dB higher than the nomogram value.) Connecting the microphone impedance and the decibel rating solves for the voltage across a matched load for the standard 10 dynes/cm² sound pressure field. By referring to the absolute sound pressure vs decibel scale, any other sound pressure level can be found and the decibel difference (with respect to 10 dynes/cm²) can be determined, and adjustments can be made in the output voltage by adding or subtracting decibels.

For high-impedance microphones, the nomogram is used in the same way, except that the impedance is always considered as 40,000 ohms, and the reading will be that for a 10 dynes/cm² field. These microphones are usually operated into a very high impedance circuit, hence 6 dB must be added to the output voltage. (Use of this method results in an error of approximately 2 dB.)



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ATTENUATOR NOMOGRAMS

These two nomograms solve for the resistor values required for the following: T, Pi, H, O, lattice, bridged T, bridged H, L, and U-type attenuators. The nomograms are based on the equations shown. The keys next to the nomograms show which scales must be used for a particular type of attenuator.

FOR EXAMPLE:

1. Z_o is 600 ohms and the required attenuation is 20 dB. Design T, H, and Pi attenuators. From nomogram 1, for a T type, R_1 is 480 ohms and R_2 is 120 ohms. For an H type each of the four series arms would be 240 ohms. For Pi type (middle key) R_2 is 750 ohms and R_3 is 3,000 ohms.

2. A lattice attenuator (key three, nomogram 1) that gives 20 dB of attenuation at 500 ohms requires R_1 to be 410 ohms and R_2 to be 610 ohms.

3. A bridged T attenuator (nomogram 2, first key) with an attenuation of 20 dB and terminal impedances of 450 ohms has R_5 as 4,000 ohms and R_6 as 50 ohms.

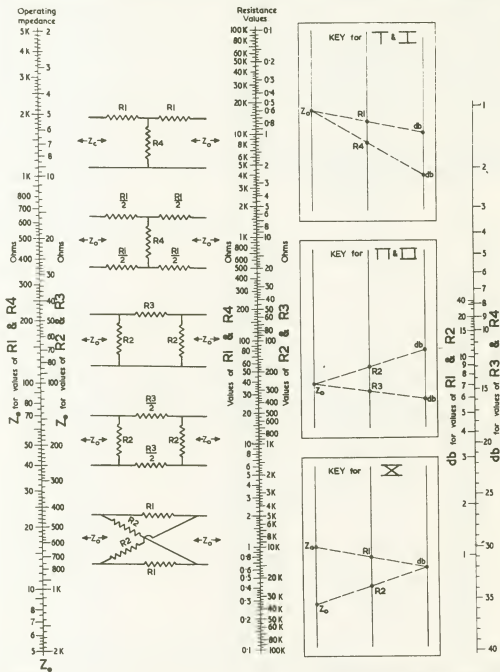
4. Design an L-type attenuator (middle key, nomogram) with an attenuation of 14 dB, and an impedance of 50 ohms with the shunt arm at the output end. In this case R_5 is 200 ohms and R_6 is 62.5 ohms.

NOTE: In all cases the input and output impedances are the same.

$$\begin{aligned}
 R_1 &= Z_o \left(\frac{K-1}{K+1} \right) & R_3 &= Z_o \left(\frac{K^2-1}{2K} \right) & R_5 &= Z_o (K-1) & R_7 &= Z_o \left(\frac{K-1}{K} \right) \\
 R_2 &= Z_o \left(\frac{K+1}{K-1} \right) & R_4 &= Z_o \left(\frac{2K}{K^2-1} \right) & R_6 &= Z_o \left(\frac{1}{K-1} \right) & R_8 &= Z_o \left(\frac{K}{K-1} \right)
 \end{aligned}$$

where $K = \frac{E_{in}}{E_{out}}$

NOMOGRAM 1 FOR T, Pi, H, O, AND LATTICE TYPE ATTENUATORS.

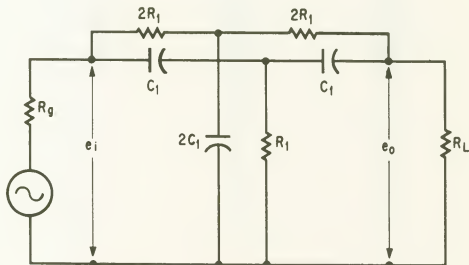


TWIN-T FILTER NOMOGRAM

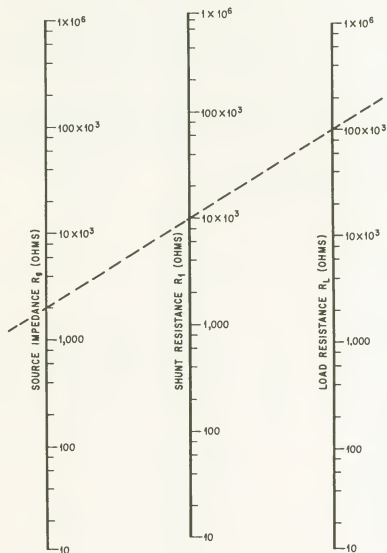
Twin-T filters with symmetrical response curves are frequently used to reject specific frequencies, or they may be included in the negative feedback loop of a frequency-selective amplifier as the tuning element. Other component combinations may be used, but the one selected here has the greatest possible selectivity. With this general configuration, any filter exhibits infinite attenuation at the notch frequency (f_o) which is specified by the values of R_1 and C_1 . If it is only desired to reject f_o , then the choice of these values is arbitrary. However, if it is desired to design a filter with a symmetrical response curve so the dc gain is equal to that at high frequencies, that is accomplished when $R_1 = \sqrt{R_g R_L} / 2$, and the notch frequency is determined by the expression $f_o = 1/4\pi C_1 R_1$. The nomograms are based on these two equations. Usually R_g , R_L , and f_o are known, and the values of R_1 and C_1 are to be determined. It is also possible to use chart 2 alone and select arbitrary values for R_1 or C_1 if symmetrical response is not essential.

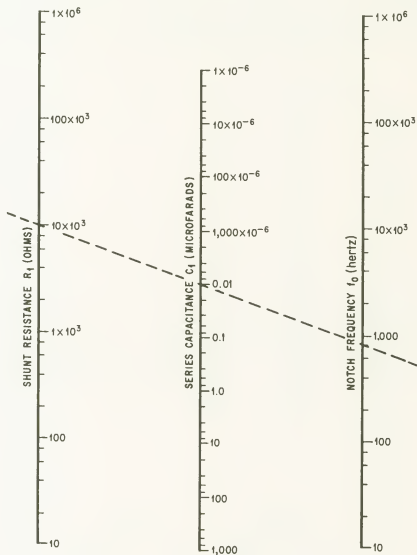
FOR EXAMPLE: Design a filter with infinite attenuation at 800 Hz which is to be inserted between a 2,000-ohm source impedance and a load resistance of 100,000 ohms. From nomogram 1 determine that R_1 should be 10,000 ohms, and with that value determine from nomogram 2 that C_1 must be 0.01 μ F to achieve a symmetrical response curve.

Twin-T notch filter, with component values related as shown, yields maximum selectivity and symmetrical gain-frequency response.



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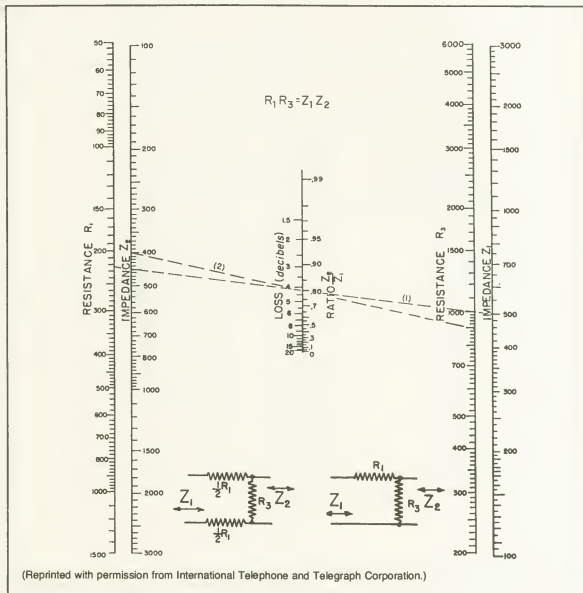


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MINIMUM-LOSS MATCHING PADS

This nomogram solves for the resistance values needed for an impedance matching pad having a minimum of attenuation. Z_1 is the greater and Z_2 is the lesser terminal impedance in ohms. To use the nomogram, calculate the ratio of Z_2/Z_1 and connect that point on the center scale with Z_1 to find R_1 , and with Z_2 to find R_3 . 890 ohms also read on the center scale.

FOR EXAMPLE: If Z_2 is 400 ohms and Z_1 is 500 ohms, the value of R_1 must be 225 ohms and of R_3 890 ohms for a minimum insertion loss pad that has 4.2 dB of insertion loss.



PREFERRED VALUES OF COMPONENTS

Preferred numbers for nominal values of resistance, capacitance, and inductance have been adopted by the electronics industry. Each value differs from its predecessor by step multiples of $(10)^{1/16}$, $(10)^{1/12}$, or $(10)^{1/24}$ resulting in incremental increase of approximately 40%, 20%, and 10% per step as shown in the table, to yield an orderly progression of component values of $\pm 20\%$, $\pm 10\%$, and $\pm 5\%$.

Standard values outside of the range listed can be obtained by multiplying by suitable multiples of 10. (For example, 15 can represent 1.5, 150, 15 k, 1.5 M, etc.)

MIL and EIA Standard for Component Values and Tolerances

$\pm 20\%$	$\pm 10\%$	$\pm 5\%$
10	10	10
		11
	12	12
		13
15	15	15
		16
	18	18
		20
22	22	22
		24
	27	27
		30
33	33	33
		36
	39	39
		43
47	47	47
		51
	56	56
		62
68	68	68
		75
	82	82
		91
100	100	100

THERMAL NOISE VOLTAGE NOMOGRAM (A)

Given frequency, input C , and amplifier input Z , only two operations are required to find the equivalent thermal noise voltage.

When an amplifier is fed from a capacitive source, the spot (one frequency) noise is generated by the real part of the impedance. This nomogram reduces the calculation required to arrive at the noise value. Impedance at the amplifier input is

$$Z = \frac{R - jR^2 \omega C}{R^2 \omega^2 C^2 + 1} \quad (1)$$

Thermal noise is generated by the real part of this expression, which is

$$(REAL Z) = \frac{R}{R^2 \omega^2 C^2 + 1} \approx \frac{1}{R \omega^2 C^2} \quad (2)$$

The mean square thermal noise voltage associated with the real part of Z is given by

$$\bar{e}^2 = 4 k T df (REAL Z) \quad (3)$$

For this case

$$df = 1 \text{ (spot frequency)} \\ T = 25^\circ\text{C}$$

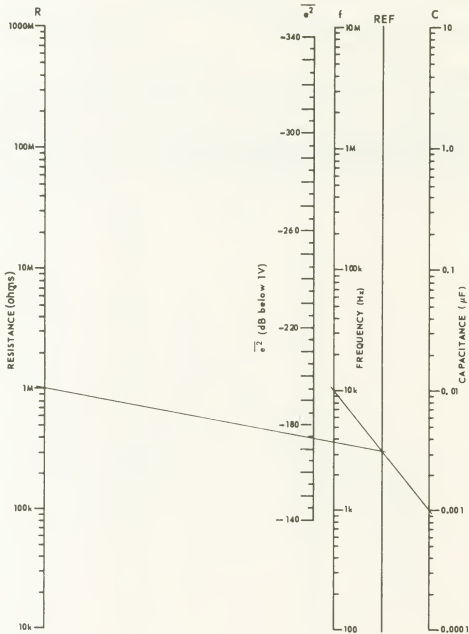
Combining (2) and (3)

$$\bar{e}^2 = 4 k T df \frac{1}{R \omega^2 C^2} \quad (4)$$

Equation (4) forms the basis for the nomogram. Nomogram of equivalent spot thermal noise voltage of the parallel combination of a capacitor and an amplifier input resistance.

Using the nomogram:

1. Choose f , C , and R (in the example $f = 10$ kHz, $C = 0.001 \mu\text{F}$, and $R = 1$ M ohm).
2. Draw a line between the chosen f and C .
3. Mark its intersection on the reference line.
4. Draw a line from the marked point on the reference scale to the chosen R .
5. The intersection of this line with the \bar{e}^2 scale is the desired equivalent thermal noise voltage in dB re 1 V.



THERMAL NOISE VOLTAGE NOMOGRAM (B)

Thermally produced noise voltage of any linear conductor is determined by Nyquist's equation

$$E = 2 \sqrt{RkTB}$$

where E = noise voltage in rms microvolts

T = absolute temperature ($^{\circ}$ K)

k = Boltzmann's constant, 1.38×10^{-23} J/ $^{\circ}$ K

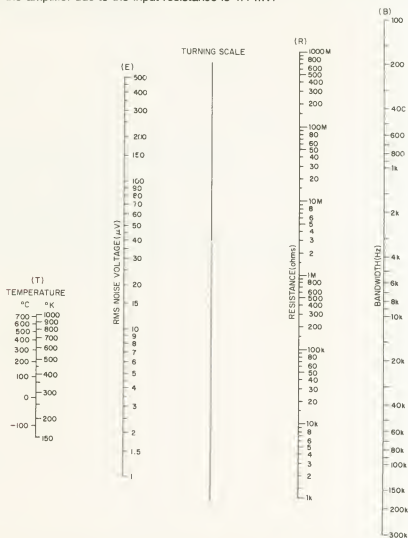
B = bandwidth in hertz

R = resistance

This nomogram solves the above equation if any three of the four variables are given.

FOR EXAMPLE: An amplifier has a voltage gain of 1,000, and input resistance of 470,000 ohms, and a bandwidth of 2 kHz. Find the output noise level due to the input resistance if the amplifier is operated at an ambient temperature of 100 $^{\circ}$ C.

Connect 100 $^{\circ}$ C (T scale) with 470 K (R scale) and note intersect point on turning scale. Connect that point with 2 kHz (B scale) and read noise voltage as 4.4 μ V on E scale. The amplifier has a gain of 1,000; thus, the outside noise of the amplifier due to the input resistance is 4.4 mV.



SINGLE-LAYER COIL DESIGN NOMOGRAM (A)

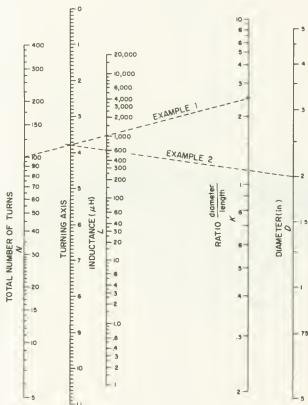
This nomogram is based on the formula for the inductance of a single-layer coil

$$L = \frac{a^2 N^2}{9a + 10b}$$

where L = inductance in microhenries
 a = coil radius in inches
 b = coil length in inches
 N = number of turns



FOR EXAMPLE: (1). Find the inductance of a 100-turn coil with a diameter of 2 in. and a winding length of 0.8 in. Find K (diameter/length) $2/0.8$ to be 2.5. Connecting 2.5 on the K scale to 100 on the N scale intersects the turning axis at 3.8. Now connect 3.8 with 2 on the D scale, and read the inductance as $600 \mu\text{H}$. (2) Determine the number of turns required for a $290\text{-}\mu\text{H}$ coil 3 in. long with a diameter of 2.5 in. K is equal to 0.8. Connect 290 on the L scale with 2.5 on the D scale, and read 4.6 on the turning axis. Connecting 4.6 and 0.8 on the K scale gives the answer as 90 turns on the N scale.

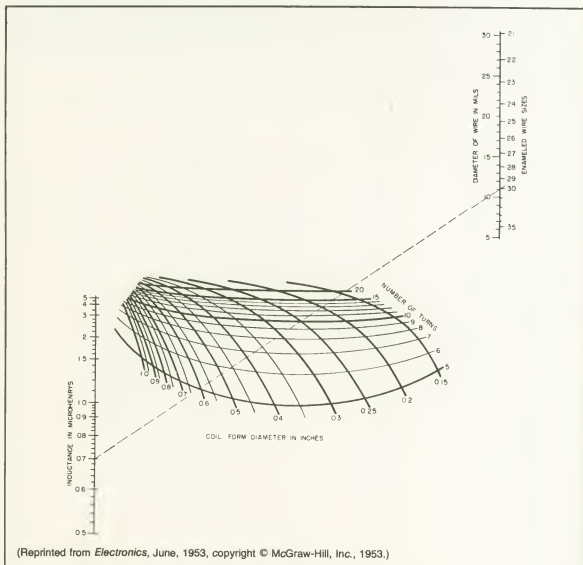


SINGLE-LAYER COIL DESIGN NOMOGRAM (B)

This nomogram solves for the number of close-wound turns required to achieve inductances in the range of values required for television, fm, and radar if transformers. The nomogram is based on a slight modification of H.A. Wheeler's inductance formula that was used to construct nomogram A. The formula used here (with all dimensions in inches) is

$$L = \frac{a^2 N^2}{8.85a + 10b}$$

FOR EXAMPLE: Ten turns of number 30 AWG enameled wire closewound on a 0.25-inch diameter coil form will produce an inductance of 0.7 μ H.

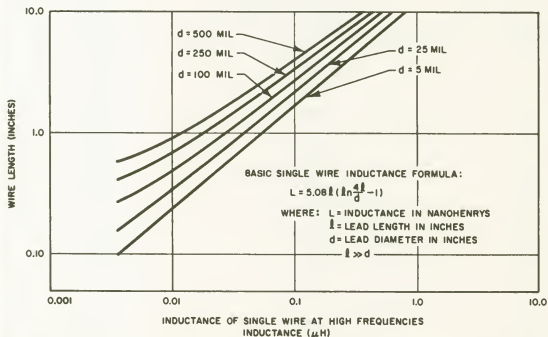


INDUCTANCE OF STRAIGHT, ROUND WIRE AT HIGH FREQUENCIES

Above several megahertz the inductance of relatively short lengths of wire becomes important because of the effect on circuit performance. The chart shows the relationship between diameter, wire length, and inductance for various diameters. A more precise tabulation is also shown for short lengths of commonly used wire sizes.

FOR EXAMPLE: A straight piece of wire 4 in. long with a diameter of 25 mil has an inductance of $0.2 \mu\text{H}$. At a frequency of 80 MHz, this represents an inductive reactance of about 100 ohms.

AWG Wire Size	Length (in.)	Approx. Inductance (μH)
20	1/4	0.0031
	1/2	0.0064
	3/4	0.0115
	1	0.019
	1 1/2	0.031
	2	0.04
24	1/4	0.0037
	1/2	0.0082
	3/4	0.014
	1	0.022
	1 1/2	0.036
	2	0.05



(From *Radio Engineers' Handbook* by Frederick E. Terman. Copyright © 1943 by McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

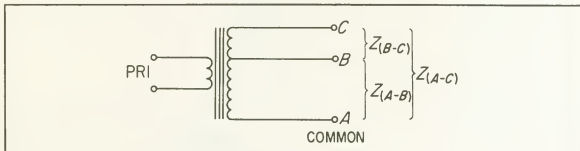
TRANSFORMER IMPEDANCE NOMOGRAM

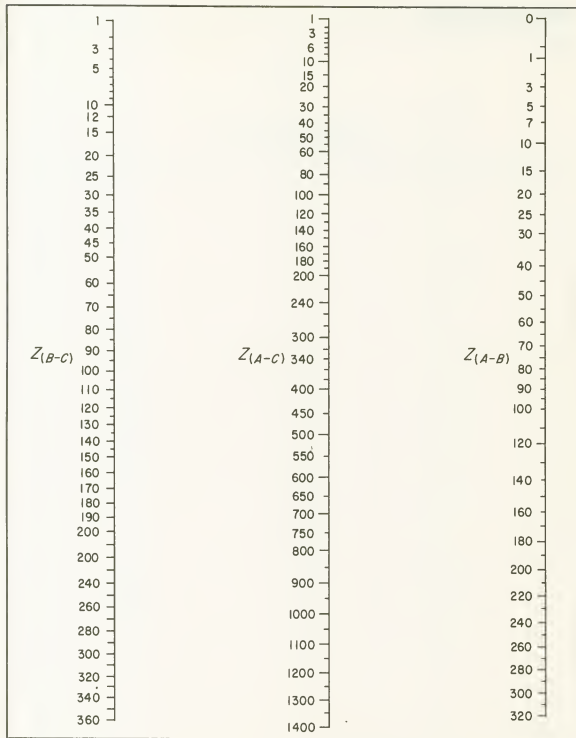
Tapped transformers provide standard impedances between the various taps and the common terminal. If a nonstandard impedance is required, it can often be found between the taps. This nomogram determines the impedance between terminals *B* and *C* if the impedance from *A* to *B* and *A* to *C* are known, and it is based on the following formula

$$Z_{(B-C)} = \left(\sqrt{Z_{(A-C)}} - \sqrt{Z_{(A-B)}} \right)^2^*$$

FOR EXAMPLE: If the impedance from *A* to *B* is 15 ohms, and the impedance from *A* to *C* is 250 ohms, then the impedance from *B* to *C* is \approx 145 ohms.

$$^* \text{Derived from } Z_{(B-C)} = Z_{A-B} \left(\sqrt{\frac{Z_{(A-C)}}{Z_{(A-B)}}} - 1 \right)^2$$





ENERGY STORAGE NOMOGRAM

The nomogram relates capacitance, charging voltage, and stored energy in a capacitor in accordance with the formula

$$J \text{ or } W = \frac{CV^2}{2}$$

where J or W = energy in joules or watt-seconds

C = capacitance in microfarad

V = charging voltage

FOR EXAMPLE: The energy stored in a 525- μ F capacitor charged to 450 V is 53 W-sec or joules.

STORED
ENERGY
(W-sec or J)



CHARGING VOLTAGE
(dc V)



CAPACITANCE
(μF)



POWER-FACTOR CORRECTION

Power factor is the ratio (usually given in percent) of the actual power used in a circuit to the power apparently drawn from the line.

$$PF = \frac{\text{actual power}}{\text{apparent power}}$$

A low power factor is undesirable, and it can be raised by the addition of power-factor correction capacitors which are rated in kVAR (kilovolt-ampere reactive). To determine the kVAR of the capacitors needed to correct from an existing to a higher power factor, multiply the proper value in the table by the average power consumption on kilowatts, of the load.

FOR EXAMPLE: Find the kVAR of capacitors that is required to raise the power factor of a 500-kW load from 70% to 85%.

From the table select the multiplying factor 0.400 which corresponds to the existing 70% and required 85% power factor. Multiplying 0.400 by 500 shows that 200 kVAR of capacitors are required.

Existing Power Factor %	Corrected Power Factor					
	100%	95%	90%	85%	80%	75%
50	1.732	1.403	1.247	1.112	0.982	0.850
52	1.643	1.314	1.158	1.023	0.893	0.761
54	1.558	1.229	1.073	0.938	0.808	0.676
55	1.518	1.189	1.033	0.898	0.768	0.636
56	1.479	1.150	0.994	0.859	0.729	0.597
58	1.404	1.075	0.919	0.784	0.654	0.522
60	1.333	1.004	0.848	0.713	0.583	0.451
62	1.265	0.936	0.780	0.645	0.515	0.383
64	1.201	0.872	0.716	0.581	0.451	0.319
65	1.168	0.839	0.683	0.548	0.418	0.286
66	1.139	0.810	0.654	0.519	0.389	0.257
68	1.078	0.749	0.593	0.458	0.328	0.196
70	1.020	0.691	0.535	0.400	0.270	0.138
72	0.964	0.635	0.479	0.344	0.214	0.082
74	0.909	0.580	0.424	0.289	0.159	0.027
75	0.882	0.553	0.397	0.262	0.132	
76	0.855	0.526	0.370	0.235	0.105	
78	0.802	0.473	0.317	0.182	0.052	
80	0.750	0.421	0.265	0.130		
82	0.698	0.369	0.213	0.078		
84	0.646	0.317	0.161			
85	0.620	0.291	0.135			
86	0.594	0.265	0.109			
88	0.540	0.211	0.055			
90	0.485	0.156				
92	0.426	0.097				
94	0.363	0.034				
95	0.329					

POWER-FACTOR NOMOGRAM

The power factor ($\cos \phi$) of a series RL or a parallel RC network is given by the following formulas

$$P.F. \text{ (inductive)} = \frac{R_2}{\sqrt{R_2^2 + (\omega L)^2}}$$

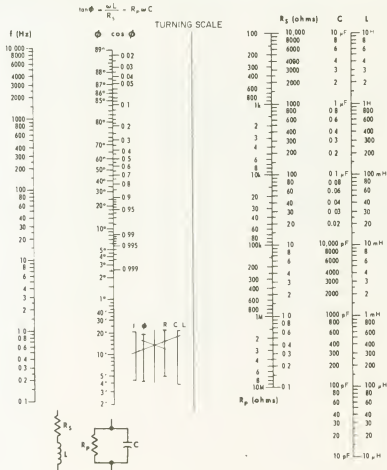
$$P.F. \text{ (capacitive)} = \frac{1}{\sqrt{(R_2 \omega C)^2 + 1}}$$

To use the nomogram connect frequency with the desired value of L or C and note the intersect point on the turning scale. Using this intersect point, connect to the resistance, and by extending this line, read power factor and phase angle.

FOR EXAMPLE:

1. A 1-H inductance in series with 100 ohms is connected to a 60-Hz source. In this case ϕ is 75° and $\cos \phi$ is 0.26.

2. An inverter operating at 2 kHz is used to supply a 100-ohm load which is in parallel with a capacitance of $0.047 \mu F$. In this case ϕ is 3.5° and $\cos \phi = 0.998$.



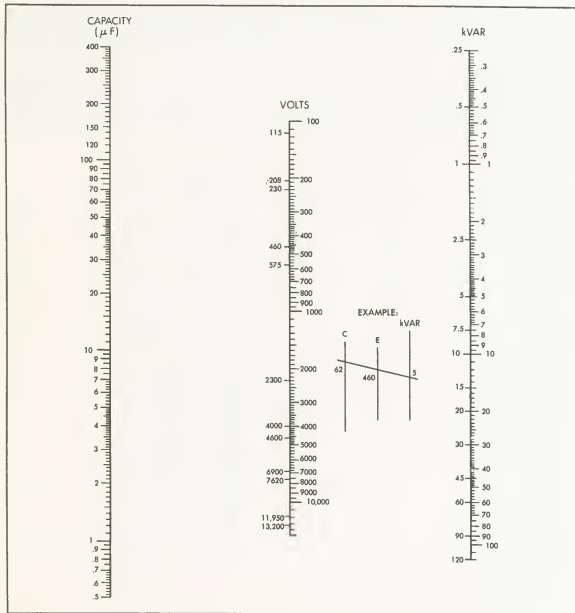
kVAR-CAPACITY NOMOGRAM FOR 60-Hz SYSTEMS

This nomogram is based on the formula

$$kVAR = \frac{2\pi f CE^2}{10^9}$$

where C is in microfarad E in volts, and f is 60 Hz.

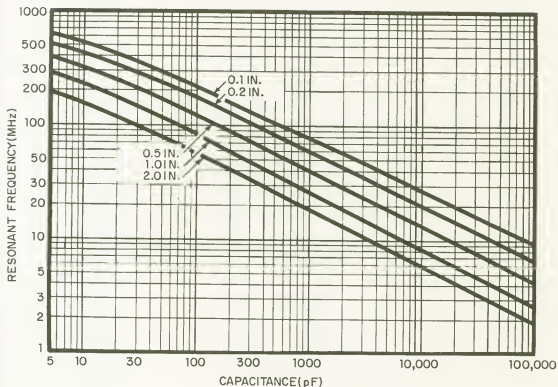
FOR EXAMPLE: To provide 5 kVAR at 460 V requires 62 μF .



SELF-RESONANT FREQUENCY OF PARALLEL LEAD CAPACITORS

The curves show the approximate self-resonant frequency of capacitors with various lead lengths. They apply to parallel lead wires of equal length #20 to #24 AWG, spaced no further than 0.375 in. apart.

FOR EXAMPLE: A 1,000-pF capacitor with 2-in. leads resonates at about 18 MHz. The same capacitor with 0.2-in. leads will resonate at 60 MHz.

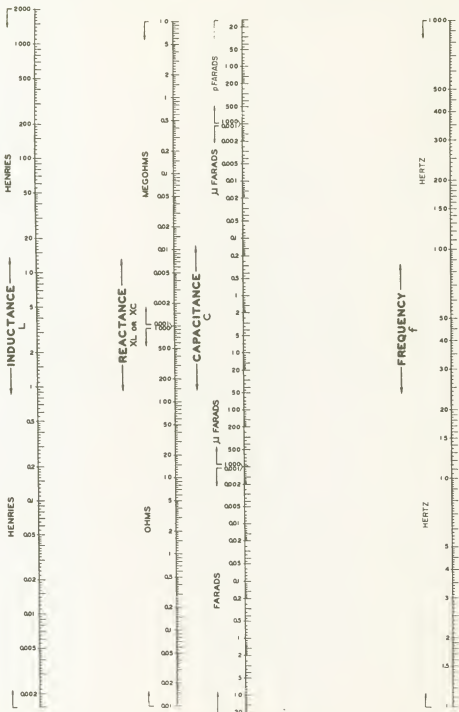


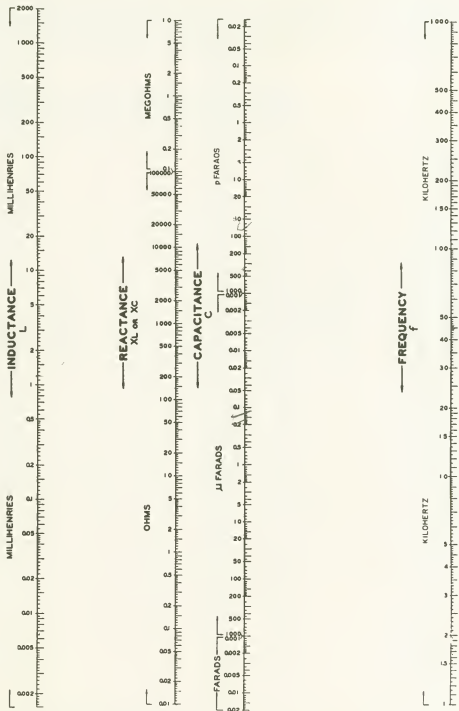
REACTANCE NOMOGRAMS

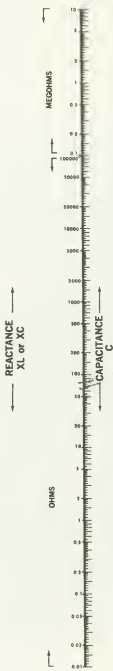
The set of three nomograms on the following pages covers the frequency range of 1 Hz to 1,000 MHz in three ranges which give direct answers without the need for additional calculations to locate the decimal point. These nomograms may be used to find capacitive reactance, inductive reactance, as well as resonant frequency ($X_L = X_C$) of any combination of inductance and capacitance.

FOR EXAMPLE:

1. The reactance of a 10-mH inductor at 10-kHz is 630 ohms.
2. The reactance of a 3-pF capacitor at 5 MHz is 10,500 ohms.
3. A 5- μ F capacitor and a 1.4-H inductance resonant at 60 Hz.



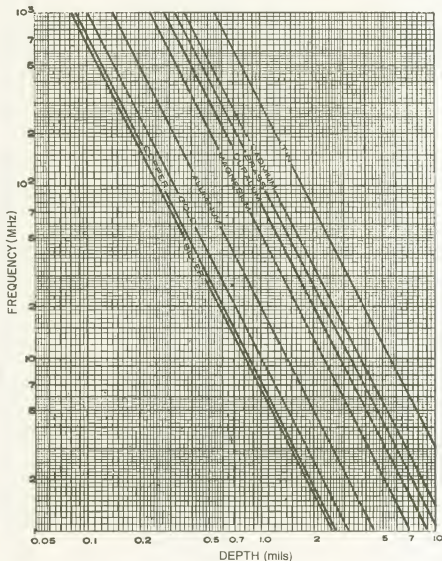














RF PENETRATION (SKIN RESISTANCE) OF VARIOUS MATERIALS








At very high frequencies current travels close to the outer surface of the conductor and eddy current losses increase beneath the surface. This effect is called "skin resistance" or "rf resistance." This chart shows the minimum required conductor depth related with frequency. The depth varies with the resistivity of the material and is least for silver. Therefore, a silver plating is frequently applied to conductors that are used at high frequencies so as to reduce the skin resistance.

FOR EXAMPLE: At 200 MHz a minimum thickness of 0.81 mils of cadmium is required, whereas only 0.16 mils of silver are needed at the same frequency.



IMPEDANCE OF SERIES-CONNECTED AND PARALLEL-CONNECTED COMBINATIONS OF L, C, AND R


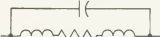










Circuit	Series combination	Impedance $Z = R + jX$	Magnitude of impedance $|Z| = \sqrt{R^2 + X^2}$	Phase angle $\phi = \tan^{-1}(X/R)$	Admittance ⁰ $Y = 1/Z$
	R	ohms R	ohms R	radians 0	mhos $1/R$
	L	$+j\omega L$	ωL	$+\pi/2$	$-j(1/\omega L)$
	C	$-j(1/\omega C)$	$1/\omega C$	$-\pi/2$	$j\omega C$
	$R_1 + R_2$	$R_1 + R_2$	$R_1 + R_2$	0	$1/(R_1 + R_2)$
	$L_1(M)L_2$	$+j\omega(L_1 + L_2 \pm 2M)$	$\omega(L_1 + L_2 \pm 2M)$	$+\pi/2$	$-j/\omega(L_1 + L_2 \pm 2M)$
	$C_1 + C_2$	$-j\omega \left(\frac{C_1 + C_2}{C_1 C_2} \right)$	$\frac{1}{\omega} \left(\frac{C_1 + C_2}{C_1 C_2} \right)$	$-\frac{\pi}{2}$	$j\omega \left(\frac{C_1 C_2}{C_1 + C_2} \right)$
	$R + L$	$R + j\omega L$	$\sqrt{R^2 + \omega^2 L^2}$	$\tan^{-1} \frac{\omega L}{R}$	$\frac{R - j\omega L}{R^2 + \omega^2 L^2}$
	$R + C$	$R - j \frac{1}{\omega C}$	$\sqrt{\frac{\omega^2 C^2 R^2 + 1}{\omega^2 C^2}}$	$-\tan^{-1} \frac{1}{\omega RC}$	$\frac{\omega^2 C^2 R + j\omega C}{\omega^2 C^2 R^2 + 1}$
	$L + C$	$+j \left(\omega L - \frac{1}{\omega C} \right)$	$\left(\omega L - \frac{1}{\omega C} \right)$	$\pm \frac{\pi}{2}$	$\frac{-j\omega C}{\omega^2 LC - 1}$
	$R + L + C$	$R + j \left(\omega L - \frac{1}{\omega C} \right)$	$\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C} \right)^2}$	$\tan^{-1} \left(\frac{\omega L - 1/\omega C}{R} \right)$	$\frac{R - j(\omega L - 1/\omega C)}{R^2 + (\omega L - 1/\omega C)^2}$

Circuit	Parallel combination	Impedance $Z = R + jX$	Magnitude of impedance $|Z| = \sqrt{R^2 + X^2}$	Phase angle $\phi = \tan^{-1}(X/R)$	Admittance ⁰ $Y = 1/Z$
	R_1, R_2	ohms $\frac{R_1 R_2}{R_1 + R_2}$	ohms $\frac{R_1 R_2}{R_1 + R_2}$	radians 0	mhos $\frac{R_1 + R_2}{R_1 R_2}$
	C_1, C_2	$-j \frac{1}{\omega(C_1 + C_2)}$	$\frac{1}{\omega(C_1 + C_2)}$	$-\frac{\pi}{2}$	$+j\omega(C_1 + C_2)$
	L, R	$\frac{\omega^2 L^2 R + j\omega LR^2}{\omega^2 L^2 + R^2}$	$\frac{\omega LR}{\sqrt{\omega^2 L^2 + R^2}}$	$\tan^{-1} \frac{R}{\omega L}$	$\frac{1}{R} - \frac{j}{\omega L}$
	R, C	$\frac{R - j\omega R^2 C}{1 + \omega^2 R^2 C^2}$	$\frac{R}{\sqrt{1 + \omega^2 R^2 C^2}}$	$\tan^{-1}(-\omega RC)$	$\frac{1}{R} + j\omega C$
	L, C	$+j \frac{\omega L}{1 - \omega^2 LC}$	$\frac{\omega L}{1 - \omega^2 LC}$	$\pm \frac{\pi}{2}$	$j \left(\omega C - \frac{1}{\omega L} \right)$
	$L_1(M)L_2$	$+j\omega \frac{L_1 L_2 - M^2}{L_1 + L_2 \mp 2M}$	$\frac{L_1 L_2 - M^2}{L_1 + L_2 \mp 2M}$	$\pm \frac{\pi}{2}$	$-j \frac{1}{\omega} \left(\frac{L_1 + L_2 \mp 2M}{L_1 L_2 - M^2} \right)$
	L, C, R	$\frac{\frac{1}{R} - j \left(\omega C - \frac{1}{\omega L} \right)}{\left(\frac{1}{R} \right)^2 + \left(\omega C - \frac{1}{\omega L} \right)^2}$	$\frac{R}{\sqrt{1 + R^2 \left(\omega C - \frac{1}{\omega L} \right)^2}}$	$\tan^{-1} - R \left(\omega C - \frac{1}{\omega L} \right)$	$\frac{1}{R} + j \left(\omega C - \frac{1}{\omega L} \right)$

FREQUENCY CHARACTERISTICS OF RESISTORS, CAPACITORS, AND INDUCTORS

Tabulated here are the effects when potentials of increasing frequency are applied to resistors, capacitors, and inductors.

As the frequency increases from dc to above resonance, the effective "look" of the component changes as shown.

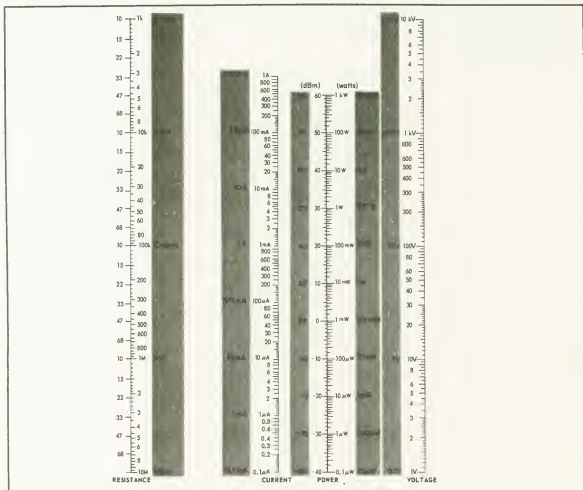
DC AND LOW FREQ.	HIGH FREQ. BELOW SELF-RESONANCE	AT SELF-RESONANCE	ABOVE SELF-RESONANCE
 $Z = R$ $X_L = 0$	 $Z = \sqrt{R^2 + X_L^2}$ $X_C \gg X_L$	 $Z = R_{\text{EQUIV.}}$ $X_C = X_L$ $R_{\text{EQUIV}} = \frac{(\omega L)^2}{R}$	 $Z = X_C$ $X_C \ll X_L$ $R \ll X_L$
 $Z = X_C$ $X_L \approx 0$ $X_C \gg R$	 $Z = \sqrt{R^2 + X_C^2}$ $X_C \gg X_L$ $X_C = R$	 $Z \approx \frac{L}{C_D R}$ $X_C = X_L$ $X_C \ll X_{CD}$	 $Z = \sqrt{R^2 + X_L^2}$ $X_L \gg X_C$
 $Z = R$ $X_L \approx 0$ $X_C = \infty$	 $Z = X_L$ $X_L \ll X_C$ $R \approx 0$	 $Z = R_{\text{EQUIV}}$ $X_C = X_L$ $R_{\text{EQUIV}} = \frac{(\omega L)^2}{R}$	 $X_C \ll X_L$ $Z \approx X_C$

RESISTANCE-VOLTAGE-CURRENT-POWER NOMOGRAM

This nomogram is based on Ohm's law, and one straight line will determine two unknown parameters if two others are given. Preferred ($\pm 20\%$) resistance values are marked in addition to the ordinary resistance scale divisions. The power scale is calibrated in watts and dBm with a reference level of 0 dBm = 1 mW into 600 ohms. This, direct conversion between dBm and watts can be made. To cover a wide range of values and yet maintain accuracy, a dual numbering system is used. To avoid confusion, all members should be read from either the regular or the gray-barred scales.

FOR EXAMPLE:

1. The current through a 150-k resistor with a potential drop of 300 V is 2 mA, and the power dissipated is 600 mW or 0.6 W.
2. When a 12,000-ohm resistor has a current of 6 mA through it, the power dissipated is 0.43 W and the voltage across the resistor is 72 V.
3. The voltage across a 4.7 M ohm resistor with a signal level of -30 dBm is about 2.15 V rms.
4. The maximum allowable current through a 10 W 200-ohm resistor is 0.22 A. Under these operating conditions there will be 45 V across the resistor.



VOLTAGE DIVIDER NOMOGRAM

This nomogram aids in the rapid selection of component values for the simple resistive and capacitive voltage dividers illustrated, where

$$\frac{e_o}{e_i} = \frac{R_g}{R_g + R_s} \quad \text{or} \quad \frac{e_o}{e_i} = \frac{C_s + C_g}{C_s}$$

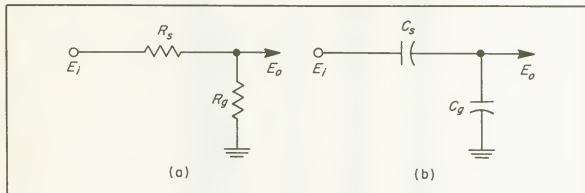
Only two decades are covered on the left and right scale to achieve maximum accuracy. The range of the nomogram can be extended by multiplying these two columns by the same power of ten without making any changes in the center column.

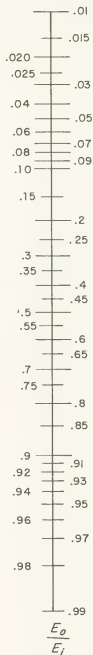
FOR EXAMPLE:

1. A blocking oscillator must be held at cutoff by means of a voltage divider between B- and ground. Cut-off bias is -15 V, the negative supply is 150 V, and the grid-to-ground resistor is $22,000$ ohms. Thus, e_o/e_i is 0.1 . Joining that value with 2.2 on the R_g scale gives 20 on the R_s scale, which makes that resistor equal to $200,000$ ohms since each scale had to be multiplied by 10^4 .

2. Design an rf probe with a $5:1$ attenuator using standard capacitance values. Rotating about the 0.2 point on the center scale gives typical values of 30 pF for C_g and 7.5 pF for C_s .

NOTE: The longer lines outside the left and right columns locate standard $\pm 10\%$ values and the shorter lines locate standard $\pm 5\%$ values.

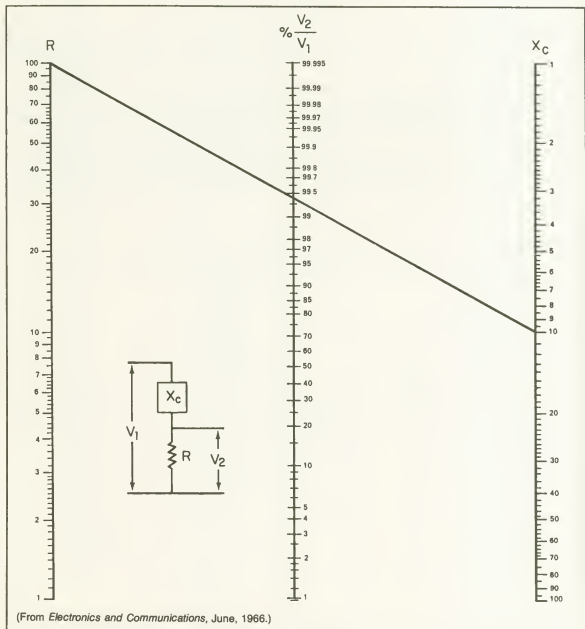




NOMOGRAM FOR CAPACITIVELY COUPLED CIRCUITS

It is often necessary to know the portion of the input voltage that will appear across the load resistor in a capacitively coupled circuit. This is a function of frequency and a factor of the ratio of R to X_c , the required ratio is shown on the center scale. It is interesting to note that any ratio of R to X_c greater than 7.4:1 yields over 99% output. The X_c and R scales can be multiplied by any common power of ten to extend the range of the nomogram.

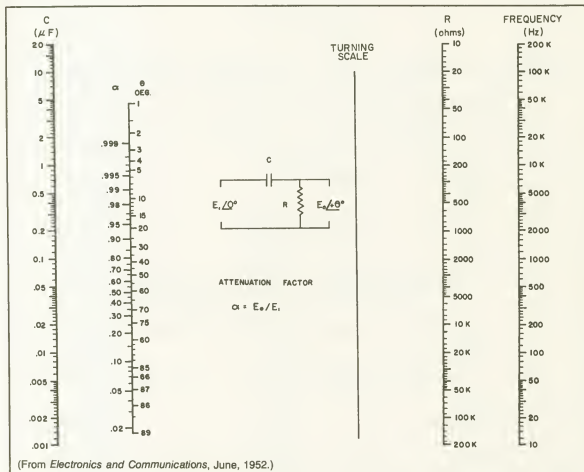
FOR EXAMPLE: For $R = 100\text{ k}$ and $X_c = 10\text{ k}$, V_2 will be 99.4% of V_1 .



R-C COUPLING NOMOGRAM













This nomogram is used to calculate phase shift and attenuation in R-C coupling networks. To use, connect capacitance with frequency and note the intersect point on the turning scale. Using this intersect point, connect to the resistance, and by extending this line, read attenuation and phase shift.

FOR EXAMPLE: At 60 Hz, a 0.01- μ F capacitor and 10,000-ohm resistor will exhibit a phase shift of 72° and an attenuation factor of 0.35.



SQUARE WAVE RESPONSE OF AMPLIFIERS

This table illustrates how performance characteristics of an amplifier can be determined by observing the waveform of the output, when the input is a square wave.

Output Waveform	Low Frequency		High Frequency		Damping
	Gain	Delay	Gain	Delay	
	Ideal	Ideal	Ideal	Ideal	Ideal
	Inadequate	Good	Excessive	Good	High
	Excessive	Good	Inadequate	Good	High
	Good	Excessive	Good	Inadequate	High
	Good	Inadequate	Good	Excessive	High
	Excessive	Excessive	Inadequate	Inadequate	High
	Excessive	Inadequate	Inadequate	Excessive	High
	Inadequate	Excessive	Excessive	Inadequate	High
	Good	Good	Excessive	Good	Medium
	Good	Good	Excessive	Good	Low
	Good	Good	Excessive	Good	Poor
	Good	Good	Sharp Cutoff or Peaked	Good	Low

LOW-END AMPLIFIER RESPONSE

In an RC-coupled amplifier, the coupling capacitance (C), combines with the output load (R), to form a potential divider or filter.

The response curve of this combination usually is specified in terms of the relative gain -3 dB point which can be calculated from the equation:

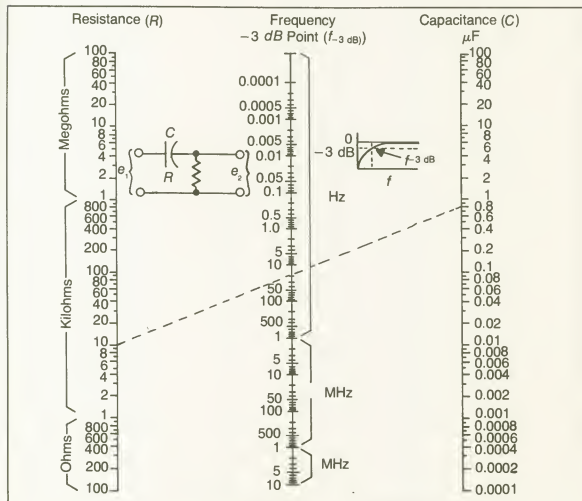
$$\frac{e_2}{e_1} = \frac{1}{\sqrt{1 + \frac{1}{(2\pi fT)^2}}} = 0.708$$

where $T = RC$ and 0.708 is used to calculate the 3 dB point.

The accompanying nomogram relates the parameters R , C or f_{-3dB} . Given any two, the third term can be determined by a simple straight-line alignment.

EXAMPLE: With a load of 10 k, what capacitance will give a low cutoff frequency of 20 Hz?

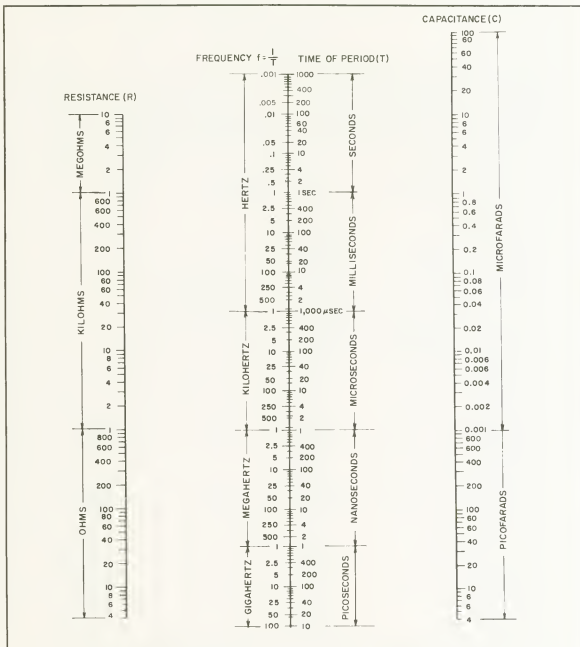
The alignment shows that a capacitor of $0.8 \mu F$ will yield the desired high-pass characteristic.



TIME-CONSTANT NOMOGRAM (A)

This nomogram is based on the formula $T = RC$ where T (the time constant) is the time required for the capacitor in an RC series circuit to reach 63.2% of the applied voltage.

FOR EXAMPLE: The time constant of 10 msec can be achieved with a 1-M ohm resistor and a 0.01- μ F capacitor.



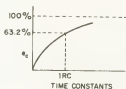
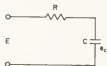
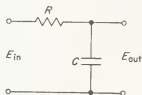
TIME-CONSTANT NOMOGRAM (B)

This chart is used to determine the time required in an RC series circuit to reach a given fraction of an applied step input, or to determine the percent of the applied input when the time constant is given.

The nomogram is based on the relationship.

$$\frac{E_{out}}{E_{in}} = 1 - e^{-t/RC}$$

FOR EXAMPLE: Determine the time required to charge a 50- μ F capacitor to 400 V through 1,000 ohms from a 450 V supply. The percent of applied voltage is 88.5% (400 / 450) which requires 2.2 time constants. The time constant is 50 ms (from time-constant nomogram A), so the time required to charge to 400 V is 110 ms.



FREQUENCY SELECTIVE NETWORK NOMOGRAM

The expression $f = 1/2\pi RC$, where f is in hertz, C and R in ohms, is the expression for:

1. The 3-dB bandwidth of a single tuned circuit having parameters as shown in Figure 1.
2. The frequency at 3 dB relative attenuation of the parallel RC low-pass network shown in Figure 2.
3. The frequency at 3 dB relative transfer attenuation of the series RC high-pass network of Figure 3.
4. Wien bridge balance.

FOR EXAMPLE:

1. The circuit shown in Figure 1 is used to couple two successive stages of an amplifier. The 3-dB bandwidth of the circuit must be 3.4 MHz and the equivalent shunt capacitance of the circuit is 25 pF. What equivalent resonant resistance will the circuit exhibit? Connect 3.4 MHz and 25 pF and find the equivalent resonant resistance as 1,850 ohms.

2. The low-pass network of Figure 2 uses a 0.05- μ F capacitor. What value of resistance is required for the output to drop to 0.707 of the input at 5 kHz? Connect 0.05- μ F with 5 kHz and read answer as 620 ohms.

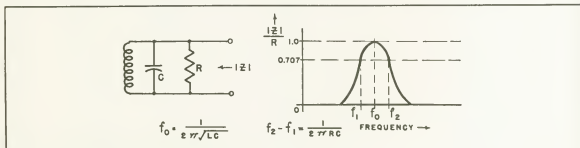


Figure 1. Characteristics of a single tuned circuit.

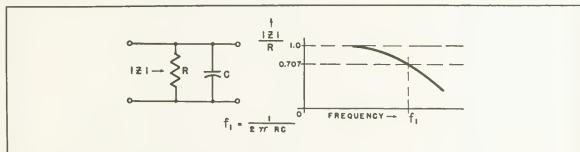


Figure 2. Characteristics of a parallel RC low-pass network.

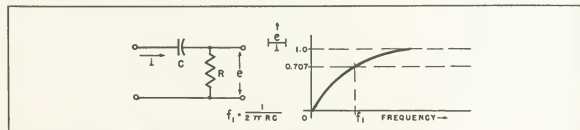


Figure 3. Transfer characteristics of an RC high-pass network.

3. It is required that the RC high-pass network in Figure 3 attenuate rapidly below 300 Hz. What value resistor must be used with a 0.1- μ F capacitor? Connect 0.1- μ F with 300 Hz (0.3 kHz) and read answer as 5,250 ohms.

4. Figure 4 shows an RC coupled amplifier and its equivalent circuits. It is assumed that the reactance of the bypass capacitors is negligible throughout the frequency range of the amplifier. If the equivalent circuit resistance has a value of 1,300 ohms and the equivalent capacitance is 25 pF, at what frequency is the amplification 0.707 of the midfrequency range of the amplifier? Connect 25 pF and 1,300 ohms and read frequency of 4.75 MHz at which amplifier gain is down 3 dB.

5. The Wien bridge circuit shown in Figure 5 has R_1 and R_3 equal to 10,000 ohms and C_1 and C_2 equal to 0.1- μ F. With those values the balance frequency of the circuit is 1.59 kHz.

$$\begin{aligned} R_1 &= R_3 = R \\ C_1 &= C_2 = C \\ \frac{R_3}{R_4} &= 2 \end{aligned}$$

For the measurement of frequency, the unknown frequency is connected across A and B and a null detector, across C and D.

When used with an oscillator, the circuit is connected to a suitable amplifier with regenerative feedback.

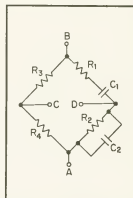
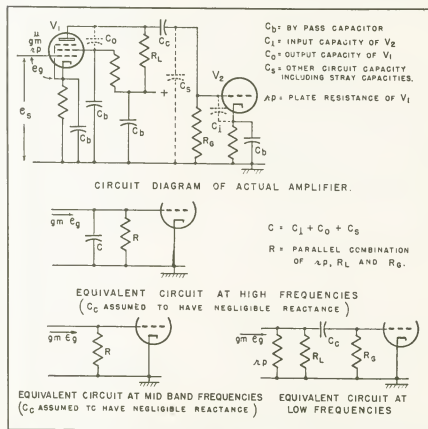


Figure 5. Conventional Wien bridge circuit.

Figure 4. An RC-coupled amplifier and its equivalent circuits.

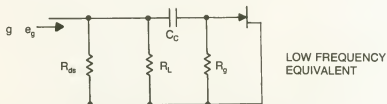
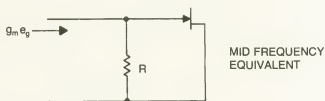
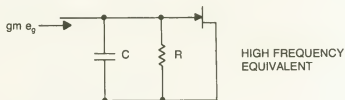
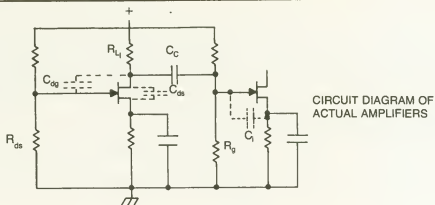
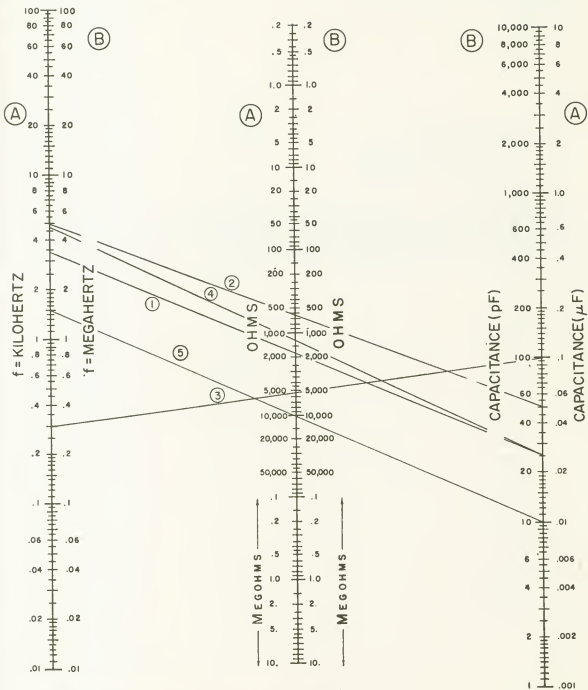


Figure 4. Circuit Diagram of N-Channel JFET Transistor Amplifier. (Continued from page 111.)



Note: Scales with corresponding letters (A or B) are used together.

BANDWIDTH NOMOGRAM

This nomogram is used to compute the bandwidth of a tuned circuit at 70.7% (−3 dB) of maximum gain. It is based on the equation

$$\Delta f = \frac{f_r}{Q}$$

where

Δf = bandwidth in kilohertz

f_r = resonant frequency in megahertz

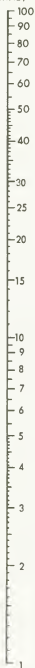
Q = figure of merit of the inductance

FOR EXAMPLE:

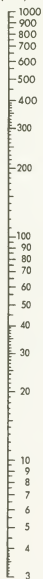
1. A circuit that has a resonant frequency of 6 MHz, and uses an inductance with a Q of 140, will have a bandwidth of 43 kHz. NOTE: The range of the nomogram can be extended to cover other frequencies by multiplying or dividing both frequency scales by the same power of 10.

2. To achieve a bandwidth of 2.5 kHz at a resonant frequency of 600 kHz the inductance must have a Q of 240.

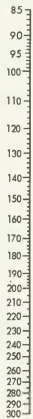
f_r
(MHz)



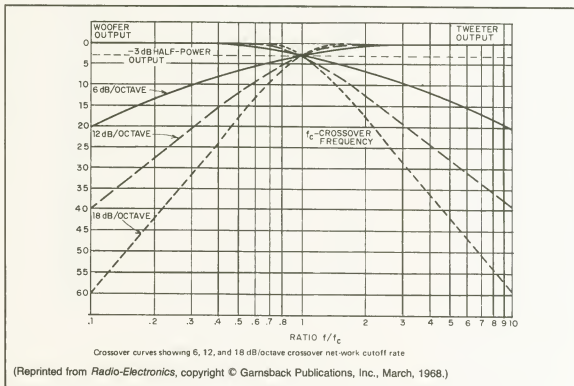
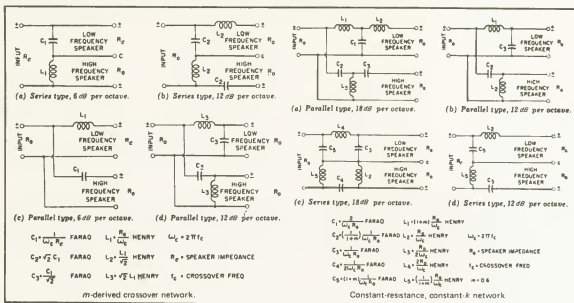
Δf
(kHz)



Q



CROSSOVER NETWORKS, DESIGN EQUATIONS, AND RATE OF ATTENUATION CURVES



PASSIVE LC FILTER DESIGN

Previous editions of the *Electronic Databook* used nomograms to determine the component values of image parameter lowpass and highpass filters. This edition provides computer-calculated tabulations of modern filter designs that are based on network synthesis. These modern designs are more versatile, less complicated and easier to build than the old image parameter designs. For example, to simplify construction, the tabulated modern filter designs require fewer components than comparable image parameter designs, and all (or most) of the capacitor values of the modern filter designs are *standard values*.

Most filtering applications do not require a precisely defined cutoff frequency, and as long as the actual cutoff frequency is within about five percent of the desired cutoff frequency, and the passband and stopband attenuation levels are satisfactory, the design will be acceptable. Of almost equal importance is finding a design that has the minimum number of components and that requires standard-value capacitors to simplify the ordering of parts and the assembly of the filter. Standard values for the inductors is less important because the inductors are usually hand-wound or ordered to specification from inductor manufacturers.

Each filter table provides many designs over one frequency decade in which the change in cutoff frequency from one design to the next is sufficiently small so that virtually any cutoff requirement can be satisfied within a few percent. The 50-ohm impedance level for source and load was used for most of the tabulations because this impedance termination is most frequently needed by the electronics engineer. All component values and frequencies versus selected stopband attenuation levels have been computer-calculated for each design for the convenience of the user. Although the tabulated designs are only for the equally terminated condition at the listed impedance level and frequency decade, a simple scaling procedure allows the tables to be scaled to *any equally terminated impedance level and any frequency decade*, while keeping the important advantage of all designs requiring only *standard-value capacitors*. These pre-calculated filter tables are therefore universally applicable because they can be used to select a suitable design having standard-value capacitors for any impedance level or any cutoff frequency.

Only the passive LC filter was considered for tabulation because this filter type is capable of passing rf power, whereas the active filter is not. Also, the passive filter does not require a power supply, and it usually is easier to assemble in small quantities than the active filter.

Filter Types and Responses

Only the lowpass and highpass filter types having the Chebyshev or elliptic attenuation responses are considered. For design information on other filter types (bandpass, bandstop, etc.), and responses (Butterworth, Bessel, etc.), see References 13-18. Only the 5th- and 7th-degree Chebyshev designs (5 and 7 elements each, respectively) and the 5th-degree elliptic design are included in the tables because these designs are suitable for almost all of the non-stringent filtering requirements encountered by the non-professional filter designer.

The Chebyshev attenuation response is characterized by attenuation ripples in the passband and a constantly (monotonic) increasing attenuation in the stopband. The level of maximum passband ripple (A_p) is directly related to the filter reflection coefficient (RC) and VSWR (see Appendix A), and these parameters can be increased or decreased to get a corresponding increase or decrease in the rate of attenuation rise in the filter stopband in the vicinity of the filter cutoff frequency.

The elliptic attenuation response is characterized by attenuation ripple in the passband, attenuation peaks in the stopband, and a specific level of minimum stopband attenuation. The presence of the two resonant circuits in the elliptic filter configuration results in a more abrupt rise in attenuation than is possible with the Chebyshev configuration.

The computer programming required for the Chebyshev and elliptic filter design tabulations was prepared by Mike Barge under the direction of Ed Wetherhold. The tables are made available for publication through the courtesy of the Signal Analysis Center of Honeywell Inc., Annapolis, MD.

Filter Tables

Lowpass and highpass filter designs are listed in ten tables, with eight tables based on a 50 ohm impedance level, and two tables (5B and 8B) based on 600 ohms. The schematic diagram and a typical attenuation response of each tabulated filter appears at the head of each table, except Tables 5B and 8B, where the only difference is the impedance level. The component designations in the schematic diagram and the frequency designations (F_{∞} , F3, F20 and F50) in the attenuation response diagram correspond to similar designations in the table column headings.

Although there is passband ripple in all these designs, the amplitude of the ripple is so small that it is usually swamped out by the losses of the filter components. Consequently, when the completed design is measured, the passband response appears to be flat. For this reason, the passband in the response diagrams is shown flat.

The filter reflection coefficient (RC) provides an indication of the flatness of the passband and the VSWR of the filter. For rf filtering applications where low VSWR is desired, designs with low reflection coefficients are preferred. For audio filtering applications, where a faster rise of attenuation is more important than minimizing VSWR, designs having high RC values are preferred.

Lowpass Filters

Chebyshev Designs and Applications. Tables 1 through 4 list 5- and 7-element Chebyshev lowpass designs. Use the 5-element designs when about 30 dB of attenuation is needed at one octave above the cutoff frequency, and the filter component count must be minimized. Use the 7-element designs when about 42 dB of attenuation is needed at one octave above the cutoff frequency. A typical application for these filters is to reduce the harmonic output of transistor amplifiers. Normally, the capacitive input/output configurations shown in Figures 1 and 3 are preferred to the alternative inductive input/output configurations in Figures 2 and 4 to minimize the number of inductors. Inductors are usually more bulky, more expensive and have higher losses than capacitors. Both filter types have identical attenuation responses, but the filter input impedances in the stopbands are markedly different. For the inductive input filter, the input impedance starts increasing between the 3 and 15-dB attenuation level, and continues increasing with increasing stopband frequency. The reverse is true for the capacitive input filter. Under certain conditions, transistor rf amplifiers may become unstable when looking into a decreasing or increasing reactive impedance (see Bibliography, Nos. 8 & 15). Because of this, it is necessary that the rf filter designer be able to design lowpass filters having either capacitive or inductive input elements.

Elliptic Designs and Applications. Tables 5A and 5B list 5th-degree elliptic lowpass designs for 50 and 600 ohms, respectively. This type of filter is preferred where a more abrupt rise in attenuation is desired. This type is also useful because the attenuation peaks at F4 and F2 sometimes can be placed at the second and third harmonic frequencies of a constant-frequency rf amplifier to provide more than 60 dB attenuation to the harmonics.

In this filter type, only capacitors C1, C3 and C5 are standard value. The fact that C2 and C4 are not standard values is not important because these capacitors should be tuned to precisely resonate L2 and L4 at F2 and F4. This is necessary if the minimum stopband attenuation level (A_{\min}) is to be achieved throughout the entire stopband. A slight variation in the values of C2, L2 and C4, L4 is not important as long as the F2 and F4 frequencies are as close as possible to the tabulated frequencies.

Table 5B is provided for audio filtering applications where this impedance level is very common. This table also serves to provide 600-ohm designs that can be used to confirm the correctness of the impedance scaling procedure to be explained later.

Highpass Filters

Chebyshev Designs and Applications. Tables 6 and 7 list 5- and 7-element Chebyshev highpass filter designs, but unlike the lowpass designs only the capacitive input/output configuration is considered. This is because they are very few applications for the alternate L-input/output configuration. The C-input/output configuration has the important advantage of increasing input impedance with decreasing frequency. This configuration is therefore suitable as an isolation network between a signal source and a detection system being used to examine the harmonics of the signal source fundamental. The highpass filter passes the harmonic frequencies unattenuated,

but provides considerable attenuation to the fundamental signal. Also, the high input impedance of the filter will not cause excessive loading of the generator. This is not true for the alternate inductive input filter.

Elliptic Designs and Applications. Tables 8A and 8B list the 5th-degree elliptic highpass designs for 50 and 600 ohms, respectively. This type filter is preferred where a more abrupt increase in attenuation is desired as compared to the Chebyshev filter. The comments concerning the elliptic lowpass design relative to C1, C3 and C5 being standard values and the importance of tuning C2 and C4 to F2 and F4 are equally applicable here. The concluding comments about the elliptic 600-ohm lowpass filter are equally applicable to the highpass filter.

How to Use the Precalculated Design Tables

For 50-Ohm Impedance Levels. Before selecting a suitable filter design, the reader must know or be able to specify the important parameters of the filter, such as type (highpass or lowpass), cutoff frequency, impedance level, and an approximation of the required stopband attenuation. It is obvious as to which tables to use for lowpass or highpass applications, but it is not so obvious as to which one design of the many possible choices is optimum for the intended application. Generally, the Chebyshev is preferred over the elliptic because the Chebyshev does not require tuning of the inductors; however, if the gradual rise in attenuation of the Chebyshev is not satisfactory, then the elliptic should be considered. For audio frequency filtering, the elliptic designs with high values of RC are preferred because they have a much more abrupt rise in attenuation as compared to the Chebyshev. For rf applications, RC values less than 8% are recommended to minimize VSWR. Low VSWR is also important when cascading high and lowpass designs to achieve a bandpass response of more than two octaves wide. Each filter will operate as expected if it is correctly terminated, but this condition will exist only if both designs have the relatively constant terminal impedance that is associated with low values of RC.

Knowing the filter type and the response needed, the table of designs most appropriate for the application is selected on a trial basis. Find the table and search the cutoff frequency column for a cutoff frequency nearest the desired cutoff frequency. After finding a possible design, examine the stopband attenuation levels to see if they are satisfactory. Then check the RC value to see if it is appropriate for the application. Finally, check the component values to see if they are convenient. Usually, it is easier to obtain capacitors with the ten-percent tolerance than the five-percent value. For example, in the audio frequency range, the capacitor values will probably be in the microfarad range, and capacitors in this size are available only in the ten-percent tolerance group.

Because all the important parameters of each design are listed, it is possible to quickly check many designs so the most suitable design can be selected. After the final choice has been made, interconnect the components in accordance with the schematic diagram above the table headings. Use good engineering practices in assembling the filter components as explained in listing number 12 of the bibliography.

For Impedance Levels Other Than 50 Ohms. All tabulated designs are easily scaled to impedance levels other than 50 ohms while maintaining the advantage of standard-value capacitors. If the impedance level differs from fifty ohms by a factor equal to an integral power of ten (such as .01, .1, 10 or 100), the design tables can be scaled by inspection (by shifting the decimal points of the component values). The tabulated frequency, A_n and RC values remain unchanged. For example, if the 50-ohm impedance level is raised by a factor of ten to 500 ohms, the new capacitance and inductance values are found by multiplying the tabulated inductance values by ten, and by dividing the capacitor values by ten. This means that the decimal points of the inductor values are shifted one place to the right, and the decimal points of the capacitor values are shifted one place to the left. The reverse is true if the impedance level is reduced from 50 to 5 ohms. For example, the impedance level of Design #1, Table 1, can be increased to 500 ohms by shifting the decimal points of L2 and L4 one place to the right (to become 107.3 μ H), and by shifting the decimal points of the capacitance values one place to the left (to become 300 pF and 560 pF).

To change the tabulated frequency decades to another frequency decade differing by a factor equal to an integral power of ten, multiply all tabulated frequencies by the factor, and divide all capacitance and inductance values by the same factor. For example, the frequency decade of Table 1 can be reduced from 1-10 MHz to 1-10 kHz by multiplying all frequencies by .001 (the frequency units in the column headings become kHz), and by

dividing the capacitance and inductance values by the same factor. (The units of capacitance and inductance become nanofarads and millihenries.)

Filter designs with standard-value capacitors may be found for impedance levels that differ from 50 ohms by a factor equal to a non-integral power of ten (such as 1.2, 12, etc.). To do this, use the following procedure:

1. Calculate the scaled impedance factor, $R = Z_x/50$ where Z_x is the desired new impedance level in ohms.
2. Calculate the cutoff frequency of a "trial" 50-ohm filter using the equation: $F_{50\infty} = R \cdot F_{x\infty}$ where $F_{x\infty}$ is the desired cutoff frequency of the filter at the new impedance level.
3. From the 50-ohm tables, select a design having its cutoff frequency closest to the calculated $F_{50\infty}$ value.

The tabulated capacitor values will be used directly, and the frequencies and inductance values will be scaled.

4. Calculate the exact values of $F_{x\infty} = F'_{50\infty}/R$, where $F'_{50\infty}$ is the tabulated cutoff frequency. In a similar manner, calculate all the other frequencies.
5. Calculate the new inductance values for the new filter from $L_x = R^2 \cdot L_{50}$, where L_{50} is the tabulated inductance value of the trial filter design, and L_x is the inductance value of the scaled filter.

An example follows showing how the 50-ohm design #3 of Table 5A can be replaced with a 60-ohm design having a similar cutoff frequency and other similar characteristics. Using the same previously numbered steps:

1. $R = 60/50 = 1.2$
2. $F_{50\infty} = 1.2(1.06 \text{ MHz}) = 1.272 \text{ MHz}$
3. From Table 5A, design #15 has a cutoff frequency closest to the calculated $F_{50\infty}$ value. The A_s and RC values are similar to design #3. Design #28 is also suitable as a replacement. The tabulated capacitor values of design #15 are copied directly. Thus, C1, 3, 5, 2 and 4 = 2,200, 3,900, 1,800, 271 and 779 pF, respectively.
4. The exact values of $F_{x\infty}$, F_{x_3} and F_{A_s} are calculated, and are equal to: $1.27 \text{ MHz}/1.2 = 1.058 \text{ MHz}$, $1.45 \text{ MHz}/1.2 = 1.208 \text{ MHz}$ and $2.17 \text{ MHz}/1.2 = 1.808 \text{ MHz}$.
5. The L2 and L4 inductance values of the 60 ohm filter are calculated: $L_2 = (1.2)^2 \cdot 7.85 \mu\text{H} = 11.3 \mu\text{H}$, $L_4 = (1.2)^2 \cdot 6.39 \mu\text{H} = 9.20 \mu\text{H}$. The validity of the scaling procedure can be confirmed by scaling the new 60-ohm filter to an impedance level of 600 ohms, and scaling the frequency from 1 MHz to 1 kHz, and then comparing the 600-ohm, 1 kHz filter with design #5 of Table 5B. All parameters of the designs will be identical, thus confirming the correctness of the scaling procedure.

The validity of the pre-calculated tables may be confirmed by independently calculating the component values using previously published normalized tables from authoritative sources such as References 8-10 and 13. This is done by finding a tabulated pre-calculated design that has a reflection coefficient nearly identical to that of a published normalized design. For example, design #80, Table 3 is suitable to match a 10% RC Chebyshev design. The pre-calculated impedance level and the cutoff frequency are then used with the normalized values, and the inductance and capacitance component values are calculated in the usual manner. Because the pre-calculated tabulated values agree within less than 1% variation with the independently calculated values, the correctness of the tables is confirmed.

APPENDIX A

Equations and Table Relating RC, A_p , and VSWR for all Modern Design Filters

$$RC_{(x)} = 100 \cdot \text{SQRT} [1 - (0.1 \uparrow x)]$$

where $100 \cdot \text{SQRT} = 100$ times the square root of . . . (1)

$$x = 0.1 (A_p)$$

\uparrow = symbol for exponentiation

* = symbol for multiplication

$$A_{p(dB)} = -4.3429 \cdot \text{LOG}[1 - (.01 \cdot RC)^2] \quad (2)$$

$$\text{VSWR} = [1 + (.01 \cdot RC)] / [1 - (.01 \cdot RC)] \quad (3)$$

where A_p = Maximum passband ripple amplitude in dB

RC = Reflection coefficient in percent

VSWR = Voltage standing wave ratio

Equations 1-3 are presented in a format suitable for computer programming. The LOG function in Eq. (2) is based on the natural log.

Table 1. Reflection Coefficient with Corresponding Values of A_p and VSWR.

REFLECTION COEFFICIENT (%)	MAX. RIPPLE AMPLITUDE (dB)	MAX. VSWR -----	REFLECTION COEFFICIENT (%)	MAX. RIPPLE AMPLITUDE (dB)	MAX. VSWR -----
1.0	0.000434	1.020	12.0	0.0630	1.273
2.0	0.001738	1.041	14.0	0.0860	1.326
3.0	0.003910	1.062	16.0	0.1126	1.381
4.0	0.006954	1.083	18.0	0.1430	1.439
5.0	0.010871	1.105	20.0	0.1773	1.500
6.0	0.015663	1.128	22.0	0.2155	1.564
7.0	0.021333	1.151	24.0	0.2576	1.632
8.0	0.027884	1.174	26.0	0.3040	1.703
9.0	0.035321	1.198	28.0	0.3546	1.778
10.0	0.043648	1.222	30.0	0.4096	1.857

References

The first four references are recommended as authoritative sources on image parameter passive LC filter design. References 5 through 18 are recommended as authoritative sources on passive LC modern filter design.

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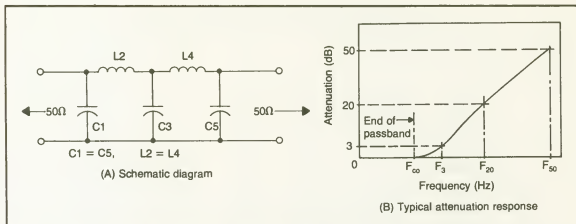


Figure 1. Lowpass filter schematic diagram and attenuation response, capacitive input and output.

Table 1. 50-ohm 5-Element Chebyshev Lowpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued on page 124.)

Filter No.	----- Cutoff	Frequency (MHz)	-----	RC (%)	C1, C5 (pf)	L2, L4 (μH)	C3 (pF)
		3-dB	20-dB	50-dB			
1	1.016	1.209	1.652	3.038	9.58	3000	5600
2	1.101	1.320	1.809	3.334	8.93	2700	5100
3	1.039	1.371	1.944	3.657	4.06	2200	4700
4	1.146	1.409	1.951	3.618	7.19	2400	4700
5	1.127	1.496	2.125	4.002	3.88	2000	4300
6	1.256	1.541	2.133	3.955	7.27	2200	4300
7	1.054	1.619	2.379	4.566	1.39	1600	8.351
8	1.232	1.646	2.344	4.420	3.67	1800	8.187
9	1.388	1.701	2.353	4.360	7.38	2000	7.754
10	1.169	1.756	2.570	4.922	1.60	1500	7.703
11	1.275	1.771	2.547	4.830	2.77	1600	7.635
12	1.462	1.825	2.542	4.731	6.30	1800	7.281
13	1.430	1.939	2.773	5.241	3.29	1500	6.960
14	1.541	1.971	2.768	5.179	5.16	1600	6.789
15	1.315	2.101	3.108	5.989	1.07	1200	6.424
16	1.481	2.117	3.065	5.836	2.26	1300	6.393
17	1.754	2.190	3.050	5.677	6.30	1500	6.067
18	1.887	2.252	3.080	5.669	9.33	1600	5.773
19	1.506	2.337	3.440	6.611	1.29	1100	5.782
20	1.700	2.361	3.396	6.441	2.77	1200	5.726
21	1.868	2.403	3.383	6.336	4.93	1300	5.573
22	1.753	2.634	3.854	7.383	1.60	1000	5.135
23	1.985	2.671	3.810	7.193	3.49	1100	5.049
24	2.193	2.737	3.813	7.096	6.30	1200	4.854
25	2.402	2.838	3.865	7.094	10.21	1300	4.549
26	1.892	2.872	4.210	8.073	1.50	910	4.709
27	2.145	2.909	4.159	7.861	3.29	1000	4.640
28	2.392	2.986	4.159	7.741	6.30	1100	4.449
29	2.053	3.157	4.639	8.906	1.38	820	4.283
30	2.362	3.201	4.575	8.646	3.31	910	4.217
31	2.631	3.284	4.575	8.515	6.30	1000	4.045

Table 1. 50-Ohm 5-Element Chebyshev Lowpass Filter designs
Using Standard-Value Capacitors, Capacitive Input and Output. (Continued from Page 123.)

Filter ----- Frequency (MHz) -----					RC	C1, C5	L2, L4	C3
No.	Cutoff	3-dB	20-dB	50-dB	(%)		(μ H)	(pF)
32	2.338	3.512	5.139	9.843	1.60	750	3.851	1800
33	2.628	3.557	5.083	9.603	3.34	820	3.794	1800
34	2.960	3.664	5.089	9.453	6.76	910	3.614	1800
35	2.705	3.959	5.763	11.01	1.92	680	3.418	1600
36	3.058	4.027	5.710	10.74	4.10	750	3.340	1600
37	3.381	4.145	5.734	10.63	7.35	820	3.182	1600
38	2.772	4.212	6.176	11.84	1.49	620	3.211	1500
39	3.135	4.265	6.101	11.54	3.22	680	3.166	1500
40	3.508	4.379	6.100	11.35	6.30	750	3.033	1500
41	3.391	4.881	7.079	13.49	2.15	560	2.772	1300
42	3.838	4.979	7.026	13.18	4.62	620	2.695	1300
43	4.259	5.147	7.080	13.08	8.32	680	2.545	1300
44	3.607	5.279	7.684	14.67	1.92	510	2.563	1200
45	4.056	5.364	7.614	14.33	3.98	560	2.509	1200
46	4.550	5.545	7.654	14.17	7.72	620	2.372	1200
47	3.963	5.762	8.376	15.98	2.01	470	2.348	1100
48	4.391	5.843	8.309	15.66	3.80	510	2.305	1100
49	4.881	6.012	8.334	15.46	7.05	560	2.198	1100
50	4.398	6.344	9.205	17.55	2.12	430	2.133	1000
51	4.907	6.448	9.135	17.18	4.18	470	2.085	1000
52	5.380	6.618	9.169	17.01	7.13	510	1.996	1000
53	4.811	6.968	10.12	19.30	2.06	390	1.942	910
54	5.426	7.095	10.04	18.86	4.34	430	1.894	910
55	5.997	7.311	10.09	18.68	7.70	470	1.799	910
56	4.862	7.690	11.36	21.86	1.14	330	1.756	820
57	5.511	7.758	11.20	21.28	2.51	360	1.743	820
58	6.066	7.887	11.14	20.90	4.54	390	1.702	820
59	6.771	8.169	11.23	20.73	8.44	430	1.602	820
60	5.262	8.404	12.43	23.95	1.07	300	1.606	750
61	6.042	8.485	12.24	23.25	2.56	330	1.594	750
62	6.702	8.645	12.18	22.82	4.83	360	1.550	750
63	7.332	8.897	12.26	22.66	8.03	390	1.475	750
64	6.687	9.363	13.49	25.62	2.61	300	1.444	680
65	7.484	9.565	13.43	25.13	5.20	330	1.398	680
66	8.254	9.896	13.57	25.00	8.93	360	1.317	680
67	7.213	10.25	14.82	28.20	2.35	270	1.320	620
68	8.181	10.48	14.73	27.57	5.10	300	1.276	620
69	9.109	10.88	14.90	27.43	9.22	330	1.195	620
70	7.818	11.32	16.45	31.37	2.06	240	1.195	560
71	9.021	11.59	16.31	30.54	4.98	270	1.155	560
72	10.16	12.09	16.52	30.38	9.58	300	1.073	560
73	8.659	12.44	18.04	34.38	2.17	220	1.087	510
74	9.636	12.65	17.91	33.67	4.22	240	1.063	510
75	9.224	13.48	19.61	37.45	1.94	200	1.003	470
76	10.39	13.71	19.44	36.57	4.06	220	0.981	470
77	9.851	14.71	21.50	41.14	1.67	180	0.919	430
78	10.54	16.19	23.79	45.66	1.39	160	0.835	390

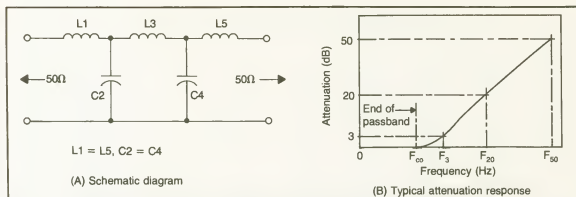


Figure 2. Lowpass filter schematic diagram and attenuation response, inductive input and output.

Table 2. 50-Ohm 5-Element Chebyshev Lowpass Filter Designs Using Standard-Value Capacitors, Inductive Input and Output.
(Continued on page 126.)

Filter No.	Frequency (MHz)	3-dB	20-dB	50-dB	RC (%)	L1, L5 (μH)	C2, C4 (pF)	L3 (μH)
1	0.74	1.15	1.69	3.25	1.32	5.6	4700	13.72
2	0.90	1.26	1.81	3.44	2.67	5.6	4300	12.66
3	1.06	1.38	1.94	3.64	4.60	5.6	3900	11.75
4	1.19	1.47	2.05	3.82	6.47	5.6	3600	11.15
5	1.32	1.58	2.17	4.00	8.76	5.6	3300	10.61
6	0.91	1.39	2.03	3.90	1.47	4.7	3900	11.38
7	1.08	1.50	2.16	4.10	2.71	4.7	3600	10.60
8	1.25	1.63	2.30	4.32	4.42	4.7	3300	9.92
9	1.42	1.77	2.46	4.56	6.65	4.7	3000	9.32
10	1.61	1.92	2.63	4.84	9.47	4.7	2700	8.79
11	1.05	1.64	2.41	4.64	1.22	3.9	3300	9.63
12	1.29	1.80	2.60	4.93	2.64	3.9	3000	8.83
13	1.54	1.99	2.80	5.25	4.73	3.9	2700	8.15
14	1.80	2.19	3.03	5.61	7.59	3.9	2400	7.57
15	1.99	2.35	3.21	5.89	10.00	3.9	2200	7.23
16	1.34	2.00	2.93	5.61	1.66	3.3	2700	7.89
17	1.68	2.25	3.20	6.03	3.69	3.3	2400	7.15
18	1.92	2.43	3.40	6.34	5.59	3.3	2200	6.72
19	2.16	2.63	3.62	6.69	7.99	3.3	2000	6.35
20	2.43	2.85	3.87	7.09	10.98	3.3	1800	6.02
21	1.66	2.46	3.59	6.87	1.72	2.7	2200	6.43
22	1.99	2.70	3.86	7.29	3.33	2.7	2000	5.93
23	2.34	2.97	4.15	7.75	5.59	2.7	1800	5.50
24	2.71	3.27	4.49	8.28	8.61	2.7	1600	5.13
25	2.92	3.44	4.68	8.58	10.44	2.7	1500	4.97

Table 2. 50-Ohm 5-Element Chebyshev Lowpass Filter Designs
Using Standard-Value Capacitors, Capacitive Input and Output. (Continued from Page 125.)

Filter -----	Frequency (MHz) -----				RC	L1, L5	C2, C4	L3
No.	Cutoff	3-dB	20-dB	50-dB	(%)	(μ H)	(pF)	(μ H)
26	2.01	3.01	4.39	8.41	1.66	2.2	1800	5.26
27	2.52	3.37	4.80	9.04	3.69	2.2	1600	4.76
28	2.78	3.57	5.02	9.39	5.07	2.2	1500	4.55
29	3.34	4.02	5.52	10.18	8.68	2.2	1300	4.18
30	3.65	4.28	5.80	10.63	10.98	2.2	1200	4.01
31	2.35	3.61	5.29	10.16	1.41	1.8	1500	4.38
32	3.12	4.14	5.89	11.10	3.83	1.8	1300	3.88
33	3.51	4.45	6.23	11.63	5.59	1.8	1200	3.67
34	3.93	4.78	6.60	12.21	7.77	1.8	1100	3.48
35	4.37	5.16	7.01	12.86	10.44	1.8	1000	3.31
36	3.10	4.51	6.56	12.51	2.00	1.5	1200	3.51
37	3.65	4.90	6.99	13.20	3.52	1.5	1100	3.27
38	4.21	5.34	7.47	13.95	5.59	1.5	1000	3.06
39	4.75	5.77	7.96	14.71	7.97	1.5	910	2.89
40	5.34	6.26	8.50	15.57	10.92	1.5	820	2.74
41	3.53	5.41	7.94	15.24	1.41	1.2	1000	2.92
42	4.30	5.94	8.53	16.17	2.89	1.2	910	2.68
43	5.09	6.53	9.19	17.20	5.02	1.2	820	2.49
44	5.73	7.04	9.75	18.09	7.18	1.2	750	2.35
45	6.42	7.62	10.39	19.09	9.87	1.2	680	2.23
46	4.40	6.60	9.65	18.48	1.63	1.0	820	2.40
47	5.27	7.20	10.32	19.53	3.09	1.0	750	2.22
48	6.15	7.87	11.06	20.70	5.13	1.0	680	2.06
49	6.95	8.51	11.77	21.81	7.39	1.0	620	1.95
50	7.80	9.22	12.56	23.05	10.21	1.0	560	1.85
51	5.23	7.96	11.67	22.38	1.48	0.82	680	1.99
52	6.33	8.72	12.51	23.70	2.95	0.82	620	1.83
53	7.45	9.56	13.45	25.18	5.03	0.82	560	1.70
54	8.44	10.35	14.32	26.55	7.31	0.82	510	1.60
55	9.28	11.05	15.10	27.76	9.54	0.82	470	1.53
56	6.41	9.66	14.15	27.10	1.57	0.68	560	1.64
57	7.75	10.59	15.18	28.73	3.09	0.68	510	1.51
58	8.83	11.41	16.08	30.15	4.76	0.68	470	1.42
59	9.97	12.31	17.08	31.72	6.88	0.68	430	1.34

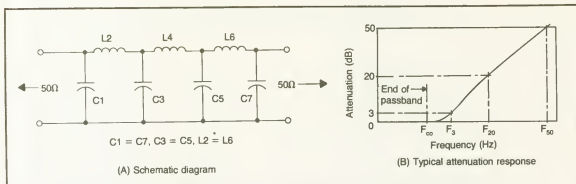


Figure 3. Lowpass filter schematic diagram and attenuation response, capacitive input and output.

Table 3. 50-ohm 7-Element Chebyshev Lowpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.

Filter No.	Cutoff	Frequency (MHz)	3-dB	20-dB	50-dB	RC (%)	C1, C7 (pF)	L2, L6 (μH)	C3, C5 (pF)	L4 (μH)
1	1.037	1.162	1.401	2.050	6.63	2700	18.90	5000	12.57	
2	1.047	1.229	1.511	2.260	3.41	2200	18.29	5100	12.29	
3	1.118	1.264	1.530	2.258	5.78	2400	10.04	5100	11.66	
4	1.033	1.299	1.633	2.486	1.46	1800	9.518	4700	11.88	
5	1.124	1.329	1.638	2.455	3.12	2000	9.502	4700	11.40	
6	1.308	1.368	1.658	2.450	5.60	2200	9.270	4700	10.78	
7	1.294	1.422	1.697	2.474	9.07	2400	8.824	4700	10.01	
8	1.101	1.412	1.785	2.731	1.16	1600	8.681	4300	10.97	
9	1.214	1.446	1.788	2.687	2.80	1800	8.709	4300	10.51	
10	1.314	1.492	1.810	2.677	5.40	2000	8.502	4300	9.910	
11	1.417	1.556	1.857	2.705	9.17	2200	8.061	4300	9.138	
12	1.250	1.566	1.967	2.894	1.51	1500	7.901	3900	9.846	
13	1.318	1.587	1.970	2.968	2.44	1600	7.910	3900	9.617	
14	1.440	1.641	1.993	2.951	5.16	1800	7.733	3900	9.035	
15	1.565	1.718	2.049	2.984	9.28	2000	7.298	3900	8.268	
16	1.445	1.726	2.135	3.210	2.71	1500	7.294	3600	8.819	
17	1.517	1.756	2.148	3.197	4.11	1600	7.219	3600	8.537	
18	1.660	1.837	2.201	3.218	8.10	1800	6.860	3600	7.826	
19	1.507	1.860	2.325	3.526	1.82	1300	6.694	3300	8.265	
20	1.682	1.929	2.350	3.487	4.71	1500	6.577	3300	7.721	
21	1.767	1.976	2.380	3.497	6.84	1600	6.403	3300	7.370	
22	1.556	2.020	2.560	3.925	1.02	1100	6.043	3000	7.682	
23	1.679	2.052	2.558	3.879	2.04	1200	6.088	3000	7.472	
24	1.786	2.092	2.570	3.841	3.51	1300	6.048	3000	7.213	
25	1.993	2.205	2.641	3.862	8.10	1500	5.716	3000	6.522	
26	1.746	2.248	2.844	4.353	1.11	1000	5.447	2700	6.894	
27	1.893	2.289	2.844	4.291	2.32	1100	5.477	2700	6.677	
28	2.032	2.341	3.053	4.263	4.11	1200	5.414	2700	6.403	
29	2.148	2.409	3.204	4.272	6.58	1300	5.258	2700	6.064	
30	2.006	2.539	3.198	4.877	1.35	910	4.856	2400	6.086	
31	2.167	2.588	3.203	4.815	2.71	1000	4.803	2400	5.879	
32	2.328	2.669	3.235	4.795	4.95	1100	4.770	2400	5.586	
33	2.491	2.756	3.301	4.827	8.10	1200	4.573	2400	5.217	
34	2.155	2.762	3.490	5.336	1.17	820	4.442	2200	5.607	
35	2.351	2.819	3.499	5.257	2.58	910	4.460	2200	5.406	
36	2.574	2.894	3.525	5.230	4.71	1000	4.384	2200	5.147	
37	2.717	3.008	3.681	5.246	8.10	1100	4.192	2200	4.782	

Table 3. 50-ohm 7-Element Chebyshev Lowpass Filter Designs
Using Standard-Value Capacitors, Capacitive Input and Output. (Continued from Page 127.)

Filter No.	Frequency (MHz)	3-dB Cutoff	20-dB	50-dB	RC (%)	C1, C7 (pF)	L2, L6 (μH)	C3, C5 (pF)	L4 (μH)
38	2.394	3.041	3.838	5.863	1.24	750	4.041	2000	5.089
39	2.568	3.094	3.840	5.788	2.43	820	4.056	2000	4.933
40	2.778	3.184	3.878	5.753	4.74	910	3.985	2000	4.676
41	2.989	3.307	3.961	5.792	8.10	1000	3.811	2000	4.348
42	2.656	3.383	4.264	6.507	1.31	680	3.640	1800	4.570
43	2.889	3.451	4.271	6.421	2.71	750	3.647	1800	4.409
44	3.090	3.539	4.310	6.393	4.78	820	3.585	1800	4.205
45	3.351	3.695	4.417	6.447	8.60	910	3.404	1800	3.871
46	3.066	3.823	4.795	7.290	1.61	620	3.243	1600	4.029
47	3.300	3.902	4.811	7.211	3.09	680	3.235	1600	3.884
48	3.552	4.022	4.873	7.196	5.65	750	3.154	1600	3.667
49	3.814	4.186	4.992	7.272	9.25	820	2.995	1600	3.394
50	3.166	4.051	5.118	7.824	1.19	560	3.029	1500	3.821
51	3.445	4.133	5.122	7.711	2.57	620	3.041	1500	3.687
52	3.694	4.240	5.168	7.671	4.64	680	2.992	1500	3.515
53	3.985	4.409	5.282	7.723	8.10	750	2.858	1500	3.261
54	3.813	4.717	5.902	8.955	1.76	510	2.636	1300	3.260
55	4.103	4.819	5.927	8.867	3.38	560	2.623	1300	3.135
56	4.429	4.983	6.019	8.865	6.23	620	2.543	1300	2.941
57	4.125	5.108	6.394	9.704	1.74	470	2.433	1200	3.011
58	4.400	5.202	6.414	9.615	3.09	510	2.426	1200	2.913
59	4.719	5.354	6.491	9.593	5.50	560	2.369	1200	2.759
60	5.120	5.606	6.677	9.713	9.66	620	2.232	1200	2.524
61	4.493	5.570	6.975	10.59	1.72	430	2.220	1100	2.762
62	4.819	5.683	7.000	10.48	3.20	470	2.222	1100	2.663
63	5.123	5.827	7.073	10.46	5.30	510	2.177	1100	2.540
64	5.516	6.067	7.245	10.56	8.93	560	2.069	1100	2.349
65	4.933	6.125	7.673	11.65	1.69	390	2.027	1000	2.513
66	5.326	6.262	7.704	11.53	3.34	430	2.018	1000	2.413
67	5.694	6.442	7.801	11.52	5.73	470	1.969	1000	2.287
68	6.077	6.608	7.974	11.62	9.01	510	1.879	1000	2.132
69	5.485	6.749	8.432	12.78	1.88	360	1.846	910	2.275
70	5.838	6.875	8.464	12.67	3.27	390	1.837	910	2.200
71	6.293	7.093	8.581	12.66	5.91	430	1.787	910	2.073
72	6.750	7.391	8.803	12.81	9.64	470	1.693	910	1.914
73	5.682	7.387	9.368	14.37	1.00	300	1.651	820	2.101
74	6.172	7.516	9.361	14.15	2.13	330	1.664	820	2.037
75	6.597	7.681	9.415	14.04	3.81	360	1.649	820	1.958
76	7.007	7.892	9.536	14.05	6.14	390	1.606	820	1.859
77	6.715	8.208	10.23	15.48	2.04	300	1.522	750	1.868
78	7.225	8.403	10.30	15.35	3.86	330	1.507	750	1.788
79	7.716	8.660	10.45	15.37	6.46	360	1.462	750	1.688
80	8.238	9.002	10.71	15.56	9.99	390	1.387	750	1.566
81	7.362	9.039	11.29	17.09	1.93	270	1.379	680	1.698
82	7.985	9.275	11.36	16.93	3.93	300	1.366	680	1.619
83	8.583	9.595	11.55	16.97	6.87	330	1.318	680	1.517
84	7.906	9.865	12.38	18.82	1.59	240	1.256	620	1.562
85	8.673	10.13	12.44	18.58	3.62	270	1.248	620	1.486
86	9.392	10.51	12.66	18.61	6.76	300	1.204	620	1.387
87	8.862	10.95	13.70	20.78	1.78	220	1.135	560	1.403
88	9.407	11.17	13.75	20.59	3.27	240	1.131	560	1.353
89	10.37	11.62	14.01	20.60	6.63	270	1.089	560	1.256
90	9.717	12.02	15.04	22.83	1.76	200	1.034	510	1.279
91	10.47	12.29	15.11	22.60	3.41	220	1.029	510	1.229
92	10.33	12.99	16.33	24.86	1.46	180	0.951	470	1.188

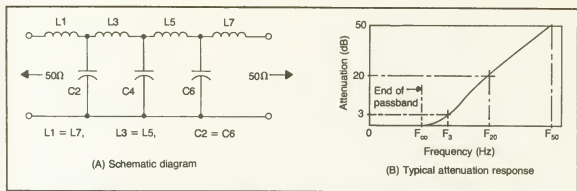


Figure 4. Lowpass filter schematic diagram and attenuation response, inductive input and output.

Table 4. 50-ohm 7-Element Chebyshev Lowpass Filter Designs Using Standard-Value Capacitors, Inductive Input and Output.

Filter No.	Frequency (MHz) Cutoff	3-dB	20-dB	50-dB	RC (%)	L1, L7 (μ H)	C2, C6 (pF)	L3, L5 (μ H)	C4 (pF)
1	1.014	1.179	1.444	2.152	3.89	5.890	4300	13.37	5100
2	1.087	1.293	1.597	2.398	2.88	5.062	3900	12.04	4700
3	1.197	1.405	1.728	2.584	3.41	4.810	3600	11.15	4300
4	1.328	1.537	1.879	2.797	4.16	4.581	3300	10.29	3900
5	1.425	1.683	2.075	3.110	3.12	3.947	3000	9.274	3600
6	1.528	1.855	2.308	3.486	2.21	3.363	2700	8.316	3300
7	1.634	2.059	2.589	3.945	1.43	2.828	2400	7.408	3000
8	1.859	2.271	2.832	4.284	2.04	2.710	2200	6.775	2700
9	2.137	2.525	3.113	4.665	3.12	2.631	2000	6.182	2400
10	2.291	2.782	3.462	5.228	2.21	2.242	1800	5.544	2200
11	2.452	3.088	3.884	5.918	1.43	1.885	1600	4.939	2000
12	2.849	3.367	4.150	6.219	3.12	1.973	1500	4.637	1800
13	3.126	3.838	4.791	7.256	1.93	1.589	1300	4.004	1600
14	3.269	4.117	5.179	7.890	1.43	1.414	1200	3.704	1500
15	3.475	3.897	4.701	6.915	6.53	2.004	1300	4.169	1500
16	3.985	4.610	5.637	8.390	4.16	1.527	1100	3.429	1300
17	4.274	5.050	6.225	9.329	3.12	1.315	1000	3.091	1200
18	4.633	5.533	6.846	10.29	2.72	1.170	910	2.807	1100
19	5.053	6.115	7.600	11.47	2.30	1.027	820	2.525	1000
20	5.581	6.702	8.309	12.51	2.53	0.953	750	2.311	910
21	6.229	7.412	9.160	13.76	2.85	0.880	680	2.098	820
22	6.791	8.119	10.05	15.11	2.68	0.795	620	1.912	750
23	7.463	8.973	11.13	16.76	2.50	0.710	560	1.725	680
24	8.176	9.847	12.22	18.41	2.44	0.644	510	1.571	620
25	9.207	10.77	13.23	19.76	3.57	0.633	470	1.457	560
26	10.14	11.79	14.44	21.52	3.89	0.589	430	1.337	510
27	10.87	12.93	15.97	23.98	2.88	0.506	390	1.203	470

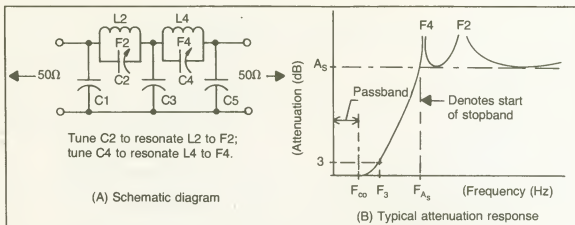


Figure 5. 50-ohm 5th-degree elliptic lowpass filter designs using standard-value capacitors for C1, C3, and C5.

Table 5A. 50-ohm 5th-Degree Elliptic Lowpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.

Filter No.	F-CO (MHz)	F-3dB (MHz)	F-As (MHz)	As (dB)	RC (%)	C1 (pF)	C3 (pF)	C5 (pF)	C2 (pF)	C4 (pF)	L2 (μH)	L4 (μH)	F2 (MHz)	F4 (MHz)
1	0.80	0.99	1.57	47.4	4.40	2700	5600	2200	324	937	12.1	10.1	2.54	1.64
2	0.93	1.09	1.67	46.7	7.15	2700	5100	2200	333	960	10.6	8.74	2.67	1.74
3	1.06	1.20	1.77	46.2	10.5	2700	4700	2200	341	982	9.36	7.56	2.82	1.85
4	1.23	1.35	1.92	45.8	15.3	2700	4300	2200	352	1010	7.93	6.27	3.02	2.00
5	1.47	1.57	2.15	45.4	22.7	2700	3900	2200	364	1045	6.32	4.88	3.32	2.23
6	0.87	1.10	1.83	49.7	3.84	2400	5100	2000	257	735	11.0	9.41	2.99	1.91
7	1.00	1.20	1.93	49.2	6.04	2400	4700	2000	262	748	9.91	8.36	3.12	2.01
8	1.16	1.33	2.06	48.6	9.37	2400	4300	2000	269	765	8.67	7.19	3.30	2.15
9	1.37	1.51	2.25	48.1	14.5	2400	3900	2000	276	785	7.25	5.90	3.55	2.34
10	1.39	1.60	3.10	61.5	10.8	3200	3900	2000	130	355	7.53	6.00	5.09	3.24
11	1.58	1.71	2.45	47.8	20.2	2400	3600	2000	284	805	6.06	4.85	3.84	2.55
12	1.62	1.80	3.37	61.3	16.0	2200	3600	2000	132	359	6.36	5.69	5.49	3.52
13	0.93	1.18	1.91	48.0	3.71	2200	4700	1800	257	743	10.2	8.59	3.11	1.99
14	1.08	1.30	2.02	47.3	6.05	2200	4300	1800	263	759	9.03	7.55	3.25	2.10
15	1.27	1.45	2.17	46.7	9.63	2200	3900	1800	271	779	7.85	6.39	3.45	2.26
16	1.45	1.61	2.32	46.3	13.8	2200	3600	1800	278	798	6.80	5.44	3.66	2.42
17	1.47	1.70	3.20	59.5	9.91	2000	3600	1800	130	357	7.07	6.33	5.24	3.35
18	1.69	1.82	2.54	45.9	19.7	2200	3300	1800	287	821	5.64	4.42	3.96	2.64
19	1.73	1.93	3.49	59.2	15.1	2000	3300	1800	132	362	5.94	5.26	5.67	3.64
20	1.00	1.27	2.00	46.1	3.57	2000	4300	1600	258	752	9.35	7.76	3.24	2.08
21	1.18	1.41	2.12	45.4	6.07	2000	3900	1600	265	771	8.27	6.73	3.40	2.21
22	1.34	1.54	2.24	44.8	8.89	2000	3600	1600	272	790	7.36	5.89	3.56	2.33
23	1.55	1.71	2.41	44.3	13.0	2000	3300	1600	280	812	6.35	4.97	3.78	2.50
24	1.56	1.82	3.32	57.3	8.91	1800	3300	1600	130	360	6.61	5.85	5.42	3.47
25	1.82	1.95	2.65	43.8	19.1	2000	3000	1600	290	841	5.21	3.99	4.09	2.75
26	1.86	2.08	3.62	57.0	14.1	1800	3000	1600	133	366	5.52	4.83	5.88	3.79

Filter No.	F-CO ----- (MHz) -----	F-3 dB -----	F-A _S -----	A _S (dB)	RC (%)	C1	C3	C5	C2	C4	L2	L4	F2	F4
				(dB)	(%)	-----	-----	-----	-----	-----	-----	-----	-----	-----
27	1.12	1.44	2.41	49.8	3.42	1800	3900	1500	192	549	8.45	7.25	3.95	2.52
28	1.28	1.56	2.53	49.3	5.41	1800	3600	1500	196	558	7.65	6.47	4.11	2.65
29	1.49	1.73	2.70	48.8	8.40	1800	3300	1500	200	570	6.75	5.62	4.33	2.81
30	1.75	1.95	2.92	48.2	13.0	1800	3000	1500	206	585	5.72	4.68	4.64	3.04
31	2.11	2.27	3.27	47.8	20.2	1800	2700	1500	213	604	4.55	3.64	5.12	3.40
32	1.16	1.54	2.51	47.7	2.70	1600	3600	1300	191	553	7.86	6.65	4.11	2.63
33	1.35	1.68	2.64	47.1	4.53	1600	3300	1300	195	564	7.10	5.92	4.28	2.75
34	1.58	1.86	2.81	46.4	7.41	1600	3000	1300	200	578	6.24	5.11	4.50	2.93
35	1.57	1.93	3.40	53.9	5.51	1500	3000	1300	129	362	6.33	5.54	5.57	3.55
36	1.88	2.11	3.05	45.8	12.0	1600	2700	1300	207	596	5.26	4.21	4.82	3.18
37	1.89	2.19	3.68	53.3	9.50	1500	2700	1300	132	369	5.39	4.65	5.96	3.84
38	2.31	2.48	3.44	45.3	19.5	1600	2400	1300	216	620	4.12	3.21	5.33	3.57
39	2.35	2.58	4.12	52.9	16.3	1500	2400	1300	136	379	4.28	3.62	6.59	4.30
40	1.28	1.66	2.63	46.3	3.11	1500	3300	1200	192	561	7.20	6.00	4.28	2.74
41	1.51	1.83	2.78	45.6	5.33	1500	3000	1200	197	574	6.42	5.25	4.47	2.90
42	1.79	2.06	2.99	44.8	8.89	1500	2700	1200	204	592	5.52	4.42	4.75	3.11
43	2.17	2.38	3.31	44.2	14.7	1500	2400	1200	212	616	4.49	3.49	5.16	3.43
44	2.52	2.70	3.63	43.8	20.8	1500	2200	1200	220	636	3.71	2.82	5.58	3.76
45	1.68	2.10	3.56	51.2	4.41	1300	2700	1100	129	365	5.79	4.99	5.83	3.73
46	2.05	2.40	3.87	50.5	8.22	1300	2400	1100	133	375	4.90	4.15	6.24	4.04
47	2.39	2.68	4.16	50.0	12.3	1300	2200	1100	136	383	4.22	3.52	6.65	4.34
48	2.84	3.08	4.60	49.7	18.6	1300	2000	1100	140	393	3.45	2.82	7.26	4.78
49	1.56	2.08	3.55	50.1	2.69	1200	2700	1000	127	363	5.88	5.07	5.83	3.71
50	1.92	2.35	3.80	49.3	5.41	1200	2400	1000	130	372	5.10	4.32	6.17	3.97
51	2.23	2.59	4.04	48.8	8.40	1200	2200	1000	133	380	4.50	3.75	6.50	4.22
52	2.62	2.92	4.38	48.2	13.0	1200	2000	1000	137	390	3.81	3.12	6.96	4.56
53	3.24	3.60	6.74	61.3	16.0	1100	1800	1000	65.9	180	3.18	2.85	11.0	7.04
54	3.17	3.41	4.90	47.8	20.2	1200	1800	1000	142	402	3.03	2.42	7.68	5.10
55	1.80	2.33	3.87	49.1	3.27	1100	2400	910	121	349	5.21	4.45	6.33	4.04
56	2.09	2.55	4.07	48.6	5.39	1100	2200	910	124	355	4.68	3.94	6.60	4.25
57	2.45	2.84	4.36	48.0	8.69	1100	2000	910	127	364	4.08	3.37	6.99	4.54
58	2.93	3.25	4.77	47.4	13.9	1100	1800	910	131	375	3.38	2.74	7.55	4.97
59	3.64	3.88	5.45	47.0	22.6	1100	1600	910	137	389	2.58	2.04	8.46	5.65
60	1.94	2.52	4.15	48.4	3.11	1000	2200	820	115	331	4.79	4.06	6.78	4.34
61	2.29	2.79	4.39	47.7	5.37	1000	2000	820	118	339	4.26	3.56	7.10	4.58
62	2.73	3.14	4.73	47.0	9.05	1000	1800	820	121	348	3.66	2.99	7.56	4.93
63	3.33	3.65	5.25	46.4	15.2	1000	1600	820	126	361	2.95	2.36	8.25	5.46
64	3.37	3.87	5.23	59.6	11.2	910	1600	820	58.8	161	3.08	2.75	11.8	7.55
65	3.73	4.02	5.63	46.2	19.7	1000	1500	820	129	368	2.56	2.01	8.76	5.85
66	3.82	4.26	7.72	59.5	15.2	910	1500	820	59.6	163	2.70	2.39	12.6	8.87
67	2.14	2.79	4.61	48.8	3.13	910	2000	750	102	294	4.35	3.71	7.55	4.82
68	2.57	3.11	4.92	48.1	5.71	910	1800	750	105	301	3.82	3.19	7.95	5.13
69	3.13	3.56	5.36	47.4	10.1	910	1600	750	108	310	3.20	2.62	8.55	5.59
70	3.49	3.87	5.68	47.1	13.4	910	1500	750	111	316	2.84	2.30	8.97	5.91
71	4.53	4.81	6.67	46.5	24.1	910	1300	750	116	331	2.04	1.60	10.3	6.92

Table 5A. 50-ohm 5th-Degree Elliptic Lowpass Filter Designs
Using Standard-Value Capacitors, Capacitive Input and Output. (Continued from Page 131.)

Filter No.	F-CO ----- (MHz) -----	F-3 dB ----- (MHz) -----	F-A _s	A _s (dB)	RC (%)	C1 -----	C3 -----	C5 (pF)	C2 -----	C4 -----	L2 --- (μH) ---	L4 ---	F2 -- (MHz) --	F4 ---
72	2.39	3.11	5.20	49.4	3.15	820	1800	680	89.3	256	3.91	3.35	8.51	5.44
73	2.93	3.52	5.59	48.6	6.14	820	1600	680	92.0	263	3.37	2.83	9.04	5.83
74	3.26	3.79	5.85	48.2	8.46	820	1500	680	93.6	267	3.07	2.54	9.39	6.10
75	4.17	4.57	6.65	47.5	16.0	820	1300	680	97.7	278	2.36	1.90	10.5	6.92
76	4.23	4.82	9.16	60.8	12.1	750	1300	680	45.8	125	2.46	2.21	15.0	9.58
77	4.83	5.17	7.30	47.2	22.1	820	1200	680	100	286	1.95	1.54	11.4	7.58
78	4.97	5.47	10.0	60.7	17.7	750	1200	680	46.4	127	2.06	1.83	16.3	10.5
79	2.74	3.49	5.73	48.9	3.75	750	1600	620	83.6	240	3.46	2.94	9.36	5.99
80	3.07	3.73	5.97	48.5	5.39	750	1500	620	84.9	243	3.19	2.68	9.67	6.23
81	3.90	4.41	6.63	47.6	10.8	750	1300	620	88.4	252	2.57	2.10	10.6	6.91
82	4.47	4.91	7.15	47.2	15.3	750	1200	620	90.6	258	2.21	1.77	11.3	7.43
83	5.24	5.61	7.89	46.9	21.8	750	1100	620	93.4	266	1.80	1.42	12.3	8.19
84	2.85	3.71	6.15	48.8	3.06	680	1500	560	76.6	220	3.26	2.78	10.1	6.43
85	3.64	4.32	6.72	47.8	6.79	680	1300	560	79.4	228	2.72	2.26	10.8	7.01
86	4.16	4.74	7.14	47.3	9.95	680	1200	560	81.3	233	2.40	1.97	11.4	7.44
87	4.82	5.31	7.72	46.9	14.5	680	1100	560	83.5	239	2.05	1.65	12.2	8.03
88	4.88	5.62	10.6	60.1	10.7	620	1100	560	39.1	107	2.13	1.91	17.4	11.1
89	5.72	6.13	8.58	46.5	21.5	680	1000	560	86.3	246	1.65	1.30	13.3	8.91
90	5.88	6.49	11.8	59.9	16.9	620	1000	560	39.8	109	1.74	1.55	19.1	12.3
91	3.41	4.28	6.93	48.3	4.15	620	1300	510	71.1	204	2.80	2.37	11.3	7.24
92	3.91	4.67	7.29	47.8	6.38	620	1200	510	72.6	208	2.53	2.10	11.8	7.61
93	4.52	5.17	7.78	47.3	9.69	620	1100	510	74.4	213	2.21	1.81	12.4	8.10
94	5.31	5.85	8.47	46.8	14.7	620	1000	510	76.7	219	1.86	1.49	13.3	8.81
95	6.29	6.73	9.40	46.4	21.6	620	910	510	79.3	226	1.50	1.18	14.6	9.76
96	3.67	4.69	7.95	50.5	3.66	560	1200	470	57.6	164	2.59	2.23	13.0	8.31
97	4.27	5.15	8.40	49.9	5.97	560	1100	470	58.8	167	2.32	1.97	13.6	8.77
98	5.02	5.77	9.01	49.4	9.57	560	1000	470	60.3	171	2.01	1.68	14.5	9.40
99	5.91	6.53	9.82	48.9	14.6	560	910	470	62.0	175	1.69	1.38	15.6	10.2
100	7.18	7.68	11.1	48.6	22.5	560	820	470	64.1	181	1.32	1.06	17.3	11.5
101	3.99	5.13	8.00	51.0	3.52	510	1100	430	51.1	145	2.38	2.06	14.4	9.20
102	4.71	5.69	9.34	50.4	6.04	510	1000	430	52.3	148	2.11	1.79	15.2	9.76
103	5.54	6.36	10.0	49.9	9.65	510	910	430	53.5	152	1.82	1.53	16.1	10.5
104	6.64	7.32	11.0	49.4	15.4	510	820	430	55.2	156	1.50	1.23	17.5	11.5
105	7.87	8.42	12.3	49.1	22.3	510	750	430	56.8	160	1.21	0.98	19.2	12.7
106	4.40	5.60	9.24	49.3	3.81	470	1000	390	51.4	147	2.16	1.84	15.1	9.66
107	5.18	6.19	9.82	48.6	6.39	470	910	390	52.6	151	1.91	1.60	15.9	10.2
108	6.17	7.01	10.6	48.0	10.5	470	820	390	54.2	155	1.63	1.34	17.0	11.1
109	7.19	7.90	11.5	47.6	15.5	470	750	390	55.7	159	1.37	1.11	18.2	12.0
110	7.30	8.34	15.9	60.9	11.7	430	750	390	26.1	71.3	1.43	1.28	26.1	16.6
111	8.63	9.20	12.9	47.3	23.2	470	680	390	57.6	164	1.09	0.86	20.1	13.4
112	8.88	9.73	17.7	60.8	18.7	430	680	390	26.6	72.4	1.15	1.02	28.8	18.5

Filter No.	F-CO ----- (MHz) -----	F-3 dB ----- (MHz) -----	F-A _S ----- (MHz) -----	A _S (dB)	RC (%)	C1 ----- (pF) -----	C3 ----- (pF) -----	C5 ----- (pF) -----	C2 ----- (pF) -----	C4 ----- (pF) -----	L2 --- (μH) ---	L4 --- (μH) ---	F2 -- (MHz) --	F4 -- (MHz) --
113	4.88	6.18	10.4	50.1	3.94	430	910	360	45.0	128	1.96	1.68	16.9	10.8
114	5.84	6.93	11.1	49.5	6.94	430	820	360	46.1	131	1.71	1.44	17.9	11.6
115	6.79	7.72	11.9	49.0	10.6	430	750	360	47.3	134	1.48	1.23	19.0	12.4
116	8.06	8.83	13.1	48.5	16.3	430	680	360	48.7	138	1.22	1.00	20.6	13.6
117	9.61	10.2	14.6	48.3	23.9	430	620	360	50.2	142	0.97	0.78	22.8	15.2
118	5.47	6.91	11.8	51.3	4.11	390	820	330	38.5	109	1.76	1.52	19.3	12.3
119	6.39	7.63	12.5	50.7	6.70	390	750	330	39.3	111	1.57	1.33	20.3	13.1
120	7.55	8.59	13.5	50.2	10.8	390	680	330	40.4	114	1.34	1.12	21.7	14.1
121	8.90	9.77	14.8	49.8	16.2	390	620	330	41.4	117	1.11	0.92	23.4	15.4
122	10.9	11.5	16.8	49.5	24.8	390	560	330	42.8	120	0.86	0.70	26.2	17.4
123	9.87	10.7	15.7	48.0	17.4	360	560	300	42.0	119	0.99	0.80	24.7	16.3
124	10.1	11.3	21.6	61.4	13.4	330	560	300	19.7	53.6	1.03	0.93	35.3	22.6
125	8.26	9.33	14.2	48.4	11.2	360	620	300	40.7	116	1.22	1.00	22.6	14.8
126	8.28	9.84	19.6	61.7	8.03	330	620	300	19.3	52.8	1.25	1.14	32.4	20.6
127	7.07	8.34	13.2	48.9	7.26	360	680	300	39.7	113	1.41	1.18	21.3	13.8
128	5.98	7.49	12.3	49.6	4.31	360	750	300	38.7	111	1.61	1.37	20.1	12.9
129	7.69	9.03	13.8	47.1	7.37	330	620	270	40.0	115	1.29	1.06	22.2	14.4
130	6.59	8.17	13.0	47.7	4.57	330	680	270	39.0	112	1.46	1.22	21.1	13.6
131	9.10	10.2	15.0	46.5	11.8	330	560	270	41.2	118	1.09	0.88	23.7	15.6
132	9.15	10.8	20.7	59.6	8.23	300	560	270	19.4	53.3	1.13	1.01	34.0	21.6
133	10.7	11.6	16.4	46.0	17.4	330	510	270	42.6	122	0.91	0.72	25.6	17.0
134	10.9	12.3	22.5	59.3	13.1	300	510	270	19.7	54.1	0.95	0.85	36.7	23.5
135	12.4	13.2	18.1	45.8	24.1	330	470	270	43.9	125	0.74	0.57	27.9	18.8
136	12.8	14.0	24.7	59.2	19.2	300	470	270	20.1	54.9	0.79	0.69	40.1	25.8
137	7.14	8.84	13.6	45.8	4.47	300	620	240	39.1	114	1.34	1.10	22.0	14.2
138	8.44	9.86	14.6	45.1	7.51	300	560	240	40.3	117	1.17	0.94	23.2	15.2
139	9.81	11.0	15.6	44.5	11.4	300	510	240	41.6	121	1.00	0.79	24.6	16.3
140	9.85	11.7	21.6	57.4	7.64	270	510	240	19.5	53.8	1.04	0.93	35.4	22.6
141	11.2	12.2	16.9	44.1	16.0	300	470	240	42.8	124	0.86	0.67	26.2	17.5
142	11.4	13.0	23.1	57.1	11.5	270	470	240	19.8	54.5	0.90	0.79	37.7	24.2
143	13.1	14.0	18.6	43.7	22.7	300	430	240	44.3	128	0.70	0.53	28.6	19.3
144	13.6	14.9	25.4	56.9	17.4	270	430	240	20.2	55.4	0.75	0.65	41.0	26.5

Table 5B. 600-Ohm 5th-Degree Elliptic Lowpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.

Filter No.	F-CO -----	F-3 dB (kHz) -----	F-A _s	A _s (dB)	RC (%)	C1	C3	C5	C2	C4	L2	L4	F2	F4
								(nF) -----			(mH) --		(kHz) --	
1	0.66	0.82	1.31	47.4	4.40	270	560	220	32.4	93.7	174	145	2.12	1.36
2	0.89	1.00	1.48	46.2	10.5	270	470	220	34.1	98.2	135	109	2.35	1.54
3	1.23	1.31	1.79	45.4	22.7	270	390	220	36.4	105	91.0	70.3	2.76	1.86
4	0.77	0.98	1.59	48.0	3.71	220	470	180	25.7	74.3	147	124	2.59	1.66
5	1.06	1.21	1.80	46.7	9.69	220	390	180	27.1	77.9	113	92.0	2.87	1.88
6	1.41	1.52	2.12	45.9	19.7	220	330	180	28.7	82.1	81.2	63.7	3.30	2.20
7	0.93	1.20	2.01	49.8	3.42	180	390	150	19.2	54.9	122	104	3.29	2.10
8	1.24	1.44	2.25	49.8	8.40	180	330	150	20.0	57.0	97.1	81.0	3.61	2.34
9	1.76	1.90	2.72	47.8	20.2	180	270	150	21.3	60.4	65.5	52.4	4.26	2.83
10	1.07	1.38	2.19	46.3	3.11	150	330	120	19.2	56.1	104	86.4	3.57	2.29
11	1.49	1.71	2.49	44.8	8.89	150	270	120	20.4	59.2	79.5	63.6	3.95	2.59
12	2.10	2.25	3.02	43.8	20.8	150	220	120	22.0	63.6	53.4	40.6	4.65	3.13
13	1.30	1.73	2.95	50.1	2.69	120	270	100	12.7	36.3	84.7	73.0	4.86	3.09
14	1.86	2.16	3.37	48.8	8.40	120	220	100	13.3	38.0	64.8	54.0	5.41	3.51
15	2.64	2.84	4.09	47.8	20.2	120	180	100	14.2	40.2	43.6	34.9	6.40	4.25
16	1.62	2.10	3.46	48.4	3.11	100	220	82	11.5	33.1	68.9	58.5	5.65	3.61
17	2.27	2.62	3.94	47.0	9.05	100	180	82	12.1	34.8	52.6	43.1	6.30	4.11
18	3.11	3.35	4.69	46.2	19.7	100	150	82	12.9	36.8	36.9	29.0	7.30	4.87
19	1.99	2.59	4.33	49.4	3.15	82	180	68	8.93	25.6	56.3	48.2	7.10	4.53
20	2.72	3.16	4.88	48.2	8.46	82	150	68	9.36	26.7	44.2	36.6	7.83	5.09
21	4.03	4.31	6.08	47.2	22.1	82	120	68	10.0	28.6	28.1	22.2	9.47	6.32
22	2.37	3.09	5.12	48.8	3.06	68	150	56	7.66	22.0	47.0	40.0	8.39	5.36
23	3.46	3.95	5.95	47.3	9.95	68	120	56	8.13	23.3	34.6	28.3	9.49	6.20
24	4.77	5.11	7.15	46.5	21.5	68	100	56	8.63	24.6	23.8	18.7	11.1	7.42
25	3.06	3.91	6.62	50.5	3.66	56	120	47	5.76	16.4	37.4	32.1	10.8	6.93
26	4.18	4.80	7.51	49.4	9.57	56	100	47	6.03	17.1	28.9	24.1	12.1	7.83
27	5.98	6.48	9.22	48.6	22.5	56	82	47	6.41	18.1	19.0	15.2	14.4	9.58
28	3.67	4.66	7.70	49.3	3.81	47	100	39	5.14	14.7	31.1	26.5	12.6	8.05
29	5.14	5.84	8.86	48.0	18.5	47	82	39	5.42	15.5	23.4	19.2	14.1	9.23
30	7.19	7.67	10.8	47.3	23.2	47	68	39	5.76	16.4	15.6	12.3	16.8	11.2
31	4.56	5.76	9.83	51.3	4.11	39	82	33	3.85	10.9	25.4	21.9	16.1	10.3
32	6.30	7.16	11.3	50.2	10.8	39	68	33	4.04	11.4	19.3	16.1	18.1	11.7
33	9.05	9.62	14.0	49.5	24.8	39	56	33	4.28	12.0	12.4	10.0	21.8	14.5
34	5.49	6.81	10.8	47.7	4.57	33	68	27	3.90	11.2	21.1	17.6	17.6	11.3
35	7.58	8.51	12.5	46.5	11.8	33	56	27	4.12	11.8	15.7	12.7	19.8	13.0
36	10.4	11.0	15.1	45.8	24.1	33	47	27	4.39	12.5	10.7	8.25	23.3	15.6

*100 nF = .1 μ F

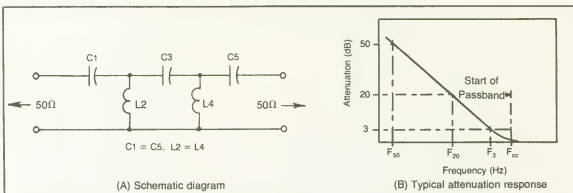


Figure 6. Highpass filter schematic diagram and attenuation response, capacitive input and output.

Table 6. 50-ohm 5-Element Chebyshev Highpass Filter Designs, Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued on Page 136.)

Filter No.	----- Frequency (MHz) -----				RC (%)	C1, C5 (pF)	L2, L4 (μH)	C3 (pF)
	Cutoff	3-dB	20-dB	50 dB				
1	1.043	0.726	0.501	0.263	2.17	5100	6.447	2200
2	1.045	0.788	0.554	0.294	3.88	4300	5.969	2000
3	1.169	0.800	0.550	0.288	1.94	4700	5.851	2000
4	1.070	0.857	0.615	0.331	6.30	3600	5.562	1800
5	1.172	0.877	0.616	0.327	3.67	3900	5.358	1800
6	1.329	0.890	0.609	0.318	1.67	4300	5.258	1800
7	1.119	0.938	0.685	0.372	9.33	3000	5.195	1600
8	1.246	0.974	0.693	0.371	5.16	3300	4.860	1600
9	1.380	0.993	0.691	0.364	2.77	3600	4.714	1600
10	1.541	1.003	0.683	0.356	1.39	3900	4.669	1600
11	1.284	1.028	0.738	0.397	6.30	3000	4.635	1500
12	1.432	1.055	0.738	0.391	3.29	3300	4.444	1500
13	1.605	1.068	0.730	0.381	1.60	3600	4.380	1500
14	1.352	1.144	0.840	0.458	10.21	2400	4.286	1300
15	1.545	1.201	0.853	0.456	4.93	2700	3.935	1300
16	1.754	1.227	0.848	0.445	2.26	3000	3.812	1300
17	1.453	1.235	0.908	0.496	10.63	2200	3.985	1200
18	1.604	1.285	0.923	0.496	6.30	2400	3.708	1200
19	1.840	1.325	0.921	0.486	2.77	2700	3.536	1200
20	2.140	1.340	0.906	0.470	1.07	3000	3.501	1200
21	1.569	1.340	0.988	0.540	11.14	2000	3.686	1100
22	1.750	1.402	1.007	0.541	6.30	2200	3.399	1100
23	1.933	1.437	1.007	0.534	3.49	2400	3.267	1100
24	2.265	1.460	0.992	0.516	1.29	2700	3.209	1100
25	1.925	1.542	1.107	0.595	6.30	2000	3.090	1000
26	2.148	1.583	1.107	0.586	3.29	2200	2.963	1000
27	2.408	1.603	1.095	0.572	1.60	2400	2.920	1000
28	2.090	1.688	1.216	0.654	6.76	1800	2.832	910
29	2.357	1.739	1.217	0.644	3.31	2000	2.697	910
30	2.675	1.762	1.202	0.627	1.50	2200	2.656	910
31	2.120	1.805	1.328	0.725	10.76	1500	2.729	820
32	2.284	1.863	1.347	0.727	7.35	1600	2.576	820
33	2.612	1.930	1.351	0.715	3.34	1800	2.431	820
34	3.009	1.957	1.332	0.694	1.38	2000	2.393	820

Table 6. 50-ohm 5-Element Chebyshev Highpass Filter Designs
Using Standard-Value Capacitors, Capacitive Input and Output. (Continued from Page 135.)

Filter No.	----- Frequency (MHz) -----				RC (%)	C1, C5 (pF)	L2, L4 (μ H)	C3 (pF)
	Cutoff	3-dB	20-dB	50 dB				
35	2.567	2.057	1.476	0.793	6.30	1500	2.317	750
36	2.762	2.097	1.479	0.786	4.10	1600	2.245	750
37	3.211	2.137	1.460	0.762	1.60	1800	2.190	750
38	2.691	2.227	1.619	0.877	8.32	1300	2.170	680
39	3.168	2.329	1.628	0.861	3.22	1500	2.013	680
40	3.443	2.352	1.616	0.846	1.92	1600	1.989	680
41	2.993	2.456	1.779	0.961	7.72	1200	1.959	620
42	3.275	2.525	1.789	0.954	4.62	1300	1.869	620
43	3.931	2.587	1.764	0.920	1.49	1500	1.809	620
44	3.370	2.736	1.974	1.064	7.05	1100	1.751	560
45	3.718	2.811	1.980	1.052	3.98	1200	1.673	560
46	4.105	2.852	1.966	1.032	2.15	1300	1.640	560
47	3.693	3.002	2.167	1.168	7.13	1000	1.596	510
48	4.113	3.091	2.174	1.154	3.80	1100	1.520	510
49	4.590	3.136	2.155	1.128	1.92	1200	1.491	510
50	3.950	3.240	2.347	1.268	7.70	910	1.485	470
51	4.393	3.343	2.360	1.255	4.18	1000	1.408	470
52	4.945	3.401	2.340	1.226	2.01	1100	1.375	470
53	4.244	3.517	2.559	1.386	8.44	820	1.375	430
54	4.772	3.650	2.580	1.373	4.34	910	1.291	430
55	5.358	3.714	2.560	1.343	2.12	1000	1.259	430
56	4.724	3.893	2.826	1.528	8.03	750	1.239	390
57	5.223	4.017	2.844	1.516	4.54	820	1.174	390
58	5.934	4.097	2.821	1.479	2.06	910	1.142	390
59	5.014	4.182	3.051	1.655	8.93	680	1.161	360
60	5.599	4.341	3.081	1.645	4.83	750	1.088	360
61	6.228	4.424	3.066	1.613	2.51	820	1.058	360
62	5.437	4.550	3.324	1.806	9.22	620	1.069	330
63	6.033	4.720	3.361	1.797	5.20	680	1.002	330
64	6.775	4.825	3.345	1.761	2.56	750	0.970	330
65	7.702	4.869	3.297	1.713	1.14	820	0.962	330
66	5.936	4.988	3.651	1.985	9.58	560	0.978	300
67	6.658	5.197	3.697	1.976	5.10	620	0.910	300
68	7.427	5.305	3.681	1.938	2.61	680	0.882	300
69	8.558	5.358	3.622	1.880	1.07	750	0.875	300
70	6.686	5.576	4.068	2.207	8.93	510	0.870	270
71	7.428	5.780	4.108	2.194	4.98	560	0.817	270
72	8.392	5.906	4.084	2.146	2.35	620	0.792	270
73	7.836	6.376	4.604	2.482	7.19	470	0.752	240
74	8.591	6.546	4.622	2.459	4.22	510	0.719	240
75	9.643	6.658	4.584	2.404	2.06	560	0.702	240
76	8.529	6.950	5.021	2.708	7.27	430	0.690	220
77	9.430	7.150	5.041	2.679	4.06	470	0.658	220
78	10.43	7.257	5.006	2.627	2.17	510	0.644	220
79	9.358	7.637	5.521	2.979	7.38	390	0.628	200
80	10.45	7.877	5.544	2.944	3.88	430	0.596	200
81	9.686	8.232	6.056	3.304	10.63	330	0.597	180
82	10.70	8.569	6.152	3.305	6.30	360	0.556	180

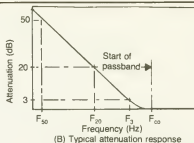
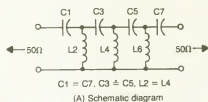


Figure 7. Highpass filter schematic diagram and attenuation response, capacitive input and output.

Table 7. 50-ohm 7-Element Chebyshev Highpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued on Page 138.)

Filter No.	----- Frequency (MHz) -----				RC (%)	C1, C7 (pF)	L2, L6 (μH)	C3, C5 (pF)	L4 (μH)
	Cutoff	3-dB	20 dB	50-dB					
1	1.022	0.826	0.660	0.435	1.76	5100	6.162	2000	4.982
2	1.002	0.880	0.724	0.489	5.16	3900	5.673	1800	4.855
3	1.079	0.905	0.732	0.487	2.80	4300	5.554	1800	4.601
4	1.159	0.922	0.734	0.482	1.46	4700	5.554	1800	4.449
5	1.086	0.971	0.806	0.549	6.84	3300	5.153	1600	4.477
6	1.160	1.002	0.819	0.550	4.11	3600	4.986	1600	4.216
7	1.232	1.023	0.824	0.547	2.44	3900	4.930	1600	4.055
8	1.338	1.043	0.825	0.539	1.16	4300	4.953	1600	3.921
9	1.130	1.021	0.853	0.583	8.10	3000	4.919	1500	4.312
10	1.217	1.061	0.871	0.587	4.71	3300	4.703	1500	4.006
11	1.299	1.087	0.879	0.584	2.71	3600	4.626	1500	3.826
12	1.386	1.106	0.880	0.578	1.51	3900	4.627	1500	3.713
13	1.344	1.198	0.994	0.676	6.58	2700	4.171	1300	3.617
14	1.455	1.242	1.011	0.676	3.51	3000	4.029	1300	3.379
15	1.567	1.270	1.016	0.670	1.82	3300	4.004	1300	3.244
16	1.413	1.277	1.066	0.729	8.10	2400	3.935	1200	3.449
17	1.546	1.336	1.092	0.734	4.11	2700	3.739	1200	3.162
18	1.677	1.372	1.100	0.727	2.04	3000	3.695	1200	3.011
19	1.541	1.393	1.163	0.795	8.10	2200	3.607	1100	3.162
20	1.649	1.443	1.186	0.800	4.95	2400	3.458	1100	2.953
21	1.802	1.490	1.200	0.795	2.32	2700	3.388	1100	2.779
22	1.973	1.520	1.199	0.782	1.02	3000	3.412	1100	2.684
23	1.695	1.532	1.279	0.875	8.10	2000	3.279	1000	2.874
24	1.825	1.592	1.307	0.881	4.71	2200	3.135	1000	2.671
25	1.948	1.631	1.318	0.877	2.71	2400	3.084	1000	2.551
26	2.150	1.669	1.320	0.862	1.11	2700	3.097	1000	2.447
27	1.846	1.674	1.400	0.959	8.60	1800	3.007	910	2.644
28	2.004	1.748	1.436	0.968	4.74	2000	2.854	910	2.432
29	2.153	1.795	1.449	0.963	2.58	2200	2.805	910	2.314
30	2.312	1.827	1.451	0.951	1.35	2400	2.810	910	2.242
31	2.025	1.845	1.547	1.062	9.25	1600	2.737	820	2.415
32	2.222	1.940	1.593	1.074	4.78	1800	2.573	820	2.193
33	2.406	1.997	1.609	1.067	2.43	2000	2.526	820	2.077
34	2.606	2.034	1.610	1.053	1.17	2200	2.538	820	2.010
35	2.260	2.043	1.705	1.166	8.10	1500	2.459	750	2.156
36	2.377	2.099	1.733	1.173	5.65	1600	2.377	750	2.045
37	2.598	2.175	1.757	1.169	2.71	1800	2.313	750	1.913
38	2.834	2.221	1.760	1.152	1.24	2000	2.319	750	1.842

Table 7. 50-ohm 7-Element Chebyshev Highpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued from Page 137.)

Filter No.	----- Frequency (MHz) ----- Cutoff	3-dB	20-dB	50-dB	RC (%)	(pF) C1, C7	L2, L6 (μH)	C3, C5 (pF)	L4 (μH)
39	2.689	2.343	1.922	1.295	4.64	1500	2.130	680	1.813
40	2.822	2.387	1.936	1.291	3.09	1600	2.101	680	1.750
41	3.105	2.447	1.941	1.272	1.31	1800	2.101	680	1.673
42	2.660	2.429	2.040	1.402	9.66	1200	2.882	620	1.842
43	2.838	2.523	2.089	1.418	6.23	1300	1.980	620	1.712
44	3.162	2.636	2.127	1.413	2.57	1500	1.911	620	1.576
45	3.331	2.671	2.130	1.401	1.61	1600	1.911	620	1.538
46	2.982	2.711	2.270	1.557	8.93	1100	1.859	560	1.638
47	3.195	2.816	2.323	1.572	5.50	1200	1.772	560	1.522
48	3.392	2.888	2.348	1.570	3.38	1300	1.734	560	1.451
49	3.810	2.977	2.357	1.542	1.19	1500	1.732	560	1.373
50	3.269	2.974	2.491	1.709	9.01	1000	1.696	510	1.494
51	3.525	3.100	2.553	1.726	5.30	1100	1.610	510	1.380
52	3.763	3.183	2.581	1.722	3.09	1200	1.576	510	1.312
53	4.008	3.240	2.589	1.706	1.76	1300	1.571	510	1.270
54	3.510	3.205	2.691	1.850	9.64	910	1.578	470	1.396
55	3.786	3.347	2.764	1.872	5.73	1000	1.491	470	1.283
56	4.067	3.449	2.800	1.869	3.20	1100	1.453	470	1.213
57	4.355	3.517	2.810	1.851	1.74	1200	1.448	470	1.170
58	4.121	3.651	3.017	2.046	5.91	910	1.367	430	1.179
59	4.424	3.763	3.058	2.044	3.34	1000	1.331	430	1.113
60	4.768	3.846	3.071	2.023	1.72	1100	1.325	430	1.070
61	4.205	3.848	3.235	2.226	9.99	750	1.317	390	1.167
62	4.521	4.015	3.322	2.255	6.14	820	1.244	390	1.074
63	4.890	4.153	3.373	2.253	3.27	910	1.206	390	1.008
64	5.267	4.242	3.386	2.230	1.69	1000	1.202	390	0.969
65	4.864	4.333	3.592	2.441	6.46	750	1.153	360	0.999
66	5.202	4.469	3.646	2.444	3.81	820	1.118	360	0.942
67	5.639	4.582	3.668	2.420	1.88	910	1.108	360	0.899
68	5.260	4.706	3.908	2.660	6.87	680	1.063	330	0.924
69	5.666	4.872	3.976	2.667	3.86	750	1.026	330	0.864
70	6.067	4.981	4.000	2.646	2.13	820	1.016	330	0.829
71	5.800	5.183	4.302	2.927	6.76	620	0.965	300	0.838
72	6.220	5.355	4.372	2.934	3.93	680	0.933	300	0.787
73	6.706	5.487	4.401	2.909	2.04	750	0.923	300	0.752
74	7.249	5.576	4.397	2.867	1.00	820	0.931	300	0.731
75	6.462	5.767	4.784	3.253	6.63	560	0.867	270	0.752
76	6.979	5.972	4.865	3.258	3.62	620	0.837	270	0.703
77	7.496	6.105	4.890	3.229	1.93	680	0.831	270	0.675
78	6.940	6.315	5.292	3.631	9.07	470	0.798	240	0.704
79	7.407	6.551	5.411	3.666	5.78	510	0.762	240	0.656
80	7.946	6.748	5.481	3.661	3.27	560	0.742	240	0.620
81	8.612	6.903	5.502	3.619	1.59	620	0.740	240	0.595
82	7.559	6.883	5.769	3.960	9.17	430	0.733	220	0.646
83	8.113	7.161	5.909	4.000	5.60	470	0.697	220	0.599
84	8.626	7.349	5.976	3.996	3.41	510	0.681	220	0.570
85	9.280	7.509	6.002	3.957	1.78	560	0.677	220	0.548
86	8.298	7.561	6.341	4.353	9.28	390	0.667	200	0.589
87	8.968	7.895	6.508	4.401	5.40	430	0.632	200	0.542
88	9.587	8.113	6.581	4.391	3.12	470	0.618	200	0.515
89	10.22	8.263	6.603	4.351	1.76	510	0.616	200	0.498
90	9.417	8.511	7.105	4.859	8.10	360	0.590	180	0.517
91	10.02	8.796	7.241	4.891	5.16	390	0.567	180	0.485
92	10.79	9.051	7.321	4.873	2.80	430	0.555	180	0.460

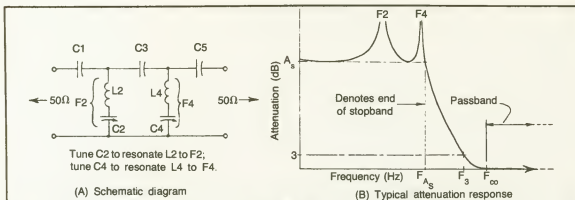


Figure 8. 50-ohm 5th degree elliptic highpass filter designs using standard-value capacitors for C1, C3 and C5.

Table 8A. 50-ohm 5th-Degree Elliptic Highpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued on Page 140.)

Filter No.	F-CO	F-3dB	F-As	As	RC	C1	C3	C5	C2	C4	L2	L4	F2	F4
	(MHz)	(MHz)	(MHz)	(dB)	(%)	(nF)	(nF)	(nF)	(nF)	(nF)	(μH)	(μH)	(MHz)	(MHz)
1	0.79	0.74	0.50	49.6	20.7	3.3	2.2	3.9	30.5	10.8	8.28	10.2	0.32	0.48
2	0.93	0.84	0.63	41.0	12.9	3.6	2.2	4.7	21.5	7.26	7.09	9.46	0.41	0.61
3	0.92	0.80	0.53	48.1	9.80	3.9	2.2	4.7	34.0	11.9	6.86	8.32	0.33	0.51
4	1.02	0.86	0.60	42.4	5.92	4.3	2.2	5.6	27.7	9.34	6.44	8.18	0.38	0.58
5	1.04	0.82	0.48	50.5	3.73	4.7	2.2	5.6	45.6	16.0	6.36	7.40	0.30	0.46
6	1.15	0.86	0.58	42.3	2.27	5.1	2.2	6.8	32.1	10.7	6.26	7.77	0.36	0.55
7	0.97	0.90	0.69	40.8	18.2	3.0	2.0	3.9	17.6	5.93	7.03	9.58	0.45	0.67
8	0.95	0.85	0.55	49.9	13.8	3.3	2.0	3.9	31.4	11.1	6.67	8.04	0.35	0.53
9	1.08	0.94	0.68	41.6	8.67	3.6	2.0	4.7	22.4	7.53	6.06	7.87	0.43	0.65
10	1.08	0.90	0.57	48.7	6.17	3.9	2.0	4.7	34.9	12.2	5.93	7.07	0.35	0.54
11	1.19	0.94	0.63	43.1	3.57	4.3	2.0	5.6	28.6	9.62	5.73	7.12	0.39	0.61
12	1.28	0.94	0.62	43.0	2.06	4.7	2.0	6.2	30.7	10.3	5.69	7.00	0.38	0.59
13	1.01	0.94	0.67	45.9	19.7	2.7	1.8	3.3	20.7	7.24	6.58	8.40	0.43	0.65
14	0.98	0.88	0.47	61.3	14.7	3.0	1.8	3.3	50.2	18.4	6.22	6.94	0.28	0.45
15	1.14	0.98	0.61	50.4	8.50	3.3	1.8	3.9	32.3	11.4	5.53	6.54	0.38	0.58
16	1.27	1.05	0.73	42.4	5.27	3.6	1.8	4.7	23.2	7.80	5.23	6.62	0.46	0.70
17	1.30	1.01	0.60	49.4	3.42	3.9	1.8	4.7	35.8	12.5	5.19	6.07	0.37	0.58
18	1.33	1.05	0.71	42.9	3.42	3.9	1.8	5.1	25.6	8.60	5.15	6.40	0.44	0.68
19	1.02	0.94	0.57	56.8	22.7	2.4	1.6	2.7	31.7	11.5	6.36	7.38	0.35	0.55
20	1.13	1.01	0.55	59.3	13.6	2.7	1.6	3.0	40.9	15.0	5.41	6.09	0.34	0.53
21	1.24	1.11	0.76	46.5	12.1	2.7	1.6	3.3	21.6	7.52	5.15	6.39	0.48	0.73
22	1.37	1.18	0.83	42.2	7.22	3.0	1.6	3.9	19.2	6.47	4.76	6.09	0.53	0.80
23	1.39	1.12	0.66	51.1	4.59	3.3	1.6	3.9	33.2	11.7	4.67	5.43	0.40	0.63
24	1.54	1.18	0.78	43.3	2.73	3.6	1.6	4.7	24.0	8.08	4.56	5.62	0.48	0.75
25	1.19	1.11	0.81	45.4	21.3	2.2	1.5	2.7	16.4	5.71	5.65	7.28	0.52	0.78
26	1.16	1.06	0.62	56.9	17.0	2.4	1.5	2.7	32.2	11.7	5.37	6.17	0.38	0.59
27	1.38	1.20	0.80	46.8	9.03	2.7	1.5	3.3	22.0	7.66	4.61	5.65	0.50	0.77
28	1.45	1.27	0.94	40.3	8.59	2.7	1.5	3.6	15.6	5.20	4.53	5.99	0.60	0.90
29	1.52	1.26	0.87	42.7	5.28	3.0	1.5	3.9	19.6	6.61	4.36	5.50	0.54	0.83
30	1.56	1.19	0.69	51.6	3.11	3.3	1.5	3.9	33.7	11.9	4.32	4.97	0.42	0.66

Table 8A. 50-Ohm 5-th Degree Elliptic Highpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued from Page 139.)

Filter No.	F-CO ----- (MHz) -----	F-3dB ----- (MHz) -----	F-A _s ----- (dB) -----	A _s (dB)	RC (%)	C1 ----- (nF) -----	C3 ----- (nF) -----	C5 ----- (nF) -----	C2 ----- (nF) -----	C4 ----- (nF) -----	L2 --- (μH) ---	L4 --- (μH) ---	F2 -- (MHz) --	F4 -- (MHz) --
31	1.29	1.23	0.91	45.7	26.9	1.8	1.3	2.2	13.4	4.68	5.43	7.08	0.59	0.87
32	1.25	1.15	0.63	61.3	21.3	2.0	1.3	2.2	33.0	12.1	5.07	5.71	0.39	0.61
33	1.53	1.37	0.94	46.1	11.9	2.2	1.3	2.7	17.2	6.00	4.17	5.19	0.59	0.90
34	1.64	1.41	0.96	45.0	7.91	2.4	1.3	3.0	17.8	6.13	3.92	4.87	0.60	0.92
35	1.75	1.40	0.88	47.8	4.37	2.7	1.3	3.3	22.9	7.95	3.77	4.50	0.54	0.84
36	1.81	1.47	1.03	41.4	4.33	2.7	1.3	3.6	16.4	5.47	3.74	4.76	0.64	0.99
37	1.51	1.40	1.01	45.9	19.7	1.8	1.2	2.2	13.8	4.82	4.39	5.60	0.65	0.97
38	1.47	1.32	0.70	61.3	14.7	2.0	1.2	2.2	33.5	12.3	4.15	4.62	0.43	0.67
39	1.61	1.44	0.96	48.2	13.0	2.0	1.2	2.4	17.5	6.16	3.93	4.81	0.61	0.93
40	1.75	1.51	1.00	46.6	8.27	2.2	1.2	2.7	17.7	6.14	3.65	4.47	0.63	0.96
41	1.87	1.54	1.01	45.6	5.33	2.4	1.2	3.0	18.2	6.27	3.51	4.29	0.63	0.97
42	2.02	1.52	0.92	48.3	2.69	2.7	1.2	3.3	23.4	8.09	3.44	4.04	0.56	0.88
43	1.42	1.33	0.81	56.9	26.0	1.6	1.1	1.8	21.0	7.65	4.66	5.43	0.51	0.78
44	1.65	1.55	1.15	43.7	21.5	1.6	1.1	2.0	10.9	3.76	4.13	5.45	0.75	1.11
45	1.60	1.44	0.80	59.2	15.7	1.8	1.1	2.0	27.1	9.92	3.86	4.36	0.49	0.77
46	1.76	1.59	1.10	46.3	13.8	1.8	1.1	2.2	14.2	4.96	3.64	4.55	0.70	1.06
47	1.87	1.61	1.04	48.7	8.74	2.0	1.1	2.4	17.9	6.30	3.38	4.06	0.65	0.99
48	2.02	1.66	1.06	47.1	5.36	2.2	1.1	2.7	18.1	6.28	3.22	3.88	0.66	1.02
49	1.48	1.38	0.66	69.6	25.8	1.5	1.0	1.6	36.6	13.7	4.32	4.69	0.40	0.63
50	1.78	1.65	1.15	47.8	20.2	1.5	1.0	1.8	12.7	4.47	3.71	4.64	0.73	1.10
51	1.92	1.65	0.88	59.5	9.91	1.8	1.0	2.0	27.6	10.1	3.18	3.55	0.54	0.84
52	2.07	1.80	1.20	46.8	9.03	1.8	1.0	2.2	14.7	5.11	3.07	3.77	0.75	1.15
53	2.18	1.91	1.41	40.3	8.59	1.8	1.0	2.4	10.4	3.47	3.02	3.99	0.90	1.35
54	2.45	1.93	1.34	40.6	3.15	2.2	1.0	3.0	12.7	4.20	2.85	3.63	0.84	1.29
55	1.93	1.81	1.34	45.1	23.5	1.3	0.91	1.6	9.45	3.29	3.56	4.64	0.87	1.29
56	2.11	1.90	1.27	48.2	13.6	1.5	0.91	1.8	13.1	4.60	3.02	3.69	0.80	1.22
57	2.09	1.82	1.02	57.1	11.0	1.6	0.91	1.8	21.9	7.94	2.93	3.33	0.63	0.98
58	2.42	2.00	1.28	47.4	5.69	1.8	0.91	2.2	15.1	5.24	2.68	3.22	0.79	1.23
59	2.51	2.10	1.50	41.0	5.55	1.8	0.91	2.4	10.8	3.59	2.65	3.41	0.94	1.44
60	2.84	2.00	1.18	48.5	1.62	2.2	0.91	2.7	19.0	6.56	2.60	3.03	0.72	1.13
61	2.22	2.08	1.55	43.7	21.0	1.2	0.82	1.5	8.19	2.83	3.05	4.02	1.01	1.49
62	2.33	2.12	1.50	45.5	15.6	1.3	0.82	1.6	9.83	3.42	2.79	3.54	0.96	1.45
63	2.32	2.17	1.39	48.7	8.49	1.5	0.82	1.8	13.5	4.73	2.51	3.01	0.87	1.33
64	2.69	2.25	1.50	45.4	6.05	1.6	0.82	2.0	12.1	4.15	2.42	2.97	0.93	1.43
65	2.89	2.23	1.36	48.2	3.15	1.8	0.82	2.2	15.5	5.37	2.36	2.78	0.83	1.30
66	2.97	2.33	1.59	41.8	3.18	1.8	0.82	2.4	11.1	3.71	2.34	2.94	0.99	1.52
67	2.27	2.12	1.45	49.6	22.7	1.1	0.75	1.3	10.1	3.59	2.93	3.62	0.93	1.40
68	2.60	2.37	1.70	44.2	14.7	1.2	0.75	1.5	8.48	2.92	2.51	3.22	1.09	1.64
69	2.56	2.26	1.37	53.2	11.4	1.3	0.75	1.5	14.6	5.24	2.42	2.82	0.85	1.31
70	2.93	2.40	1.48	49.2	5.35	1.5	0.75	1.8	13.8	4.82	2.20	2.61	0.91	1.42
71	3.12	2.47	1.58	46.0	3.74	1.6	0.75	2.0	12.4	4.25	2.16	2.61	0.97	1.51
72	3.42	2.43	1.43	48.8	1.71	1.8	0.75	2.2	15.8	5.47	2.14	2.50	0.86	1.36
73	2.57	2.40	1.68	47.8	21.9	1.0	0.68	1.2	8.40	2.96	2.60	3.27	1.08	1.62
74	2.49	2.26	1.17	63.2	17.1	1.1	0.68	1.2	20.1	7.40	2.46	2.73	0.72	1.12
75	3.05	2.68	1.85	44.7	9.72	1.2	0.68	1.5	8.77	3.02	2.10	2.64	1.17	1.78
76	3.05	2.56	1.48	53.6	7.02	1.3	0.68	1.5	14.9	5.34	2.05	2.36	0.91	1.42

Filter No.	F-CO	F-3dB	F-A _s	A _s (dB)	RC (%)	C1	C3	C5	C2	C4	L2	L4	F2	F4
-----	(MHz)	-----	-----	(dB)	(%)	-----	-----	(nF)	-----	-----	(μH)	---	(MHz)	---
77	3.48	2.66	1.57	49.9	3.06	1.5	0.68	1.8	14.1	4.94	1.96	2.28	0.96	1.50
78	3.80	2.83	1.93	40.7	2.08	1.6	0.68	2.2	9.25	3.04	1.93	2.44	1.19	1.85
79	2.45	2.29	1.28	61.6	26.5	0.91	0.62	1.0	15.0	5.54	2.67	3.02	0.79	1.23
80	2.76	2.50	1.34	61.3	17.1	1.0	0.62	1.1	16.6	6.11	2.24	2.50	0.82	1.29
81	3.04	2.76	1.87	48.1	14.9	1.0	0.62	1.2	8.66	3.05	2.10	2.58	1.18	1.79
82	3.26	2.97	2.22	41.2	13.8	1.0	0.62	1.3	6.04	2.04	2.03	2.70	1.44	2.14
83	3.54	2.97	1.98	45.3	6.30	1.2	0.62	1.5	9.03	3.11	1.83	2.25	1.24	1.90
84	4.16	2.91	1.65	50.6	1.60	1.5	0.62	1.8	14.4	5.03	1.78	2.04	1.00	1.57
85	3.17	2.96	2.13	46.1	21.7	0.82	0.56	1.0	6.31	2.21	2.13	2.72	1.37	2.05
86	3.66	3.33	2.52	40.2	13.2	0.91	0.56	1.2	5.24	1.76	1.81	2.44	1.64	2.43
87	3.62	3.16	2.05	48.6	9.51	1.0	0.56	1.2	8.93	3.14	1.74	2.10	1.28	1.96
88	3.84	3.17	1.92	50.8	6.00	1.1	0.56	1.3	11.0	3.87	1.66	1.94	1.18	1.84
89	4.19	3.30	2.11	46.1	3.64	1.2	0.56	1.5	9.30	3.19	1.61	1.94	1.30	2.02
90	4.57	3.45	2.38	40.2	2.28	1.3	0.56	1.8	7.35	2.40	1.59	2.02	1.47	2.28
91	3.47	3.24	2.31	46.6	21.5	0.75	0.51	0.91	5.93	2.08	1.93	2.46	1.49	2.23
92	3.75	3.40	2.36	46.4	14.9	0.82	0.51	1.0	6.52	2.28	1.72	2.15	1.50	2.27
93	4.22	3.71	2.72	40.9	8.97	0.91	0.51	1.2	5.44	1.82	1.55	2.03	1.73	2.61
94	4.24	3.52	2.19	49.2	6.00	1.0	0.51	1.2	9.16	3.21	1.51	1.79	1.35	2.10
95	5.03	3.72	2.47	42.4	2.05	1.2	0.51	1.6	7.59	2.52	1.45	1.80	1.52	2.36
96	5.45	3.74	2.49	41.0	1.16	1.3	0.51	1.8	7.56	2.47	1.46	1.81	1.52	2.38
97	3.68	3.45	2.45	47.2	23.2	0.68	0.47	0.82	5.53	1.95	1.84	2.33	1.58	2.36
98	4.02	3.67	2.53	46.9	15.4	0.75	0.47	0.91	6.10	2.14	1.60	2.00	1.61	2.44
99	4.30	3.79	2.55	46.9	10.4	0.82	0.47	1.0	6.69	2.33	1.48	1.82	1.60	2.45
100	4.79	4.05	2.87	41.5	6.18	0.91	0.47	1.2	5.60	1.88	1.38	1.77	1.81	2.76
101	4.89	3.84	2.31	49.7	3.81	1.0	0.47	1.2	9.34	3.27	1.36	1.59	1.41	2.21
102	5.87	3.89	2.31	47.4	1.05	1.2	0.47	1.5	9.71	3.32	1.35	1.58	1.39	2.20
103	4.02	3.78	2.70	46.9	23.4	0.62	0.43	0.75	4.95	1.74	1.69	2.15	1.74	2.60
104	4.34	3.97	2.72	47.5	16.1	0.68	0.43	0.82	5.70	2.00	1.48	1.84	1.73	2.62
105	4.98	4.42	3.30	40.0	9.83	0.75	0.43	1.0	4.28	1.43	1.32	1.76	2.12	3.18
106	4.98	4.21	2.73	47.4	6.86	0.82	0.43	1.0	6.87	2.39	1.28	1.55	1.69	2.61
107	5.51	4.42	3.03	42.2	3.91	0.91	0.43	1.2	5.77	1.93	1.23	1.55	1.89	2.91
108	5.76	4.20	2.42	50.3	2.14	1.0	0.43	1.2	9.53	3.33	1.23	1.42	1.47	2.31
109	4.44	4.17	3.01	46.5	23.6	0.56	0.39	0.68	4.37	1.53	1.54	1.97	1.94	2.90
110	4.82	4.40	3.03	47.2	15.7	0.62	0.39	0.75	5.12	1.80	1.34	1.66	1.92	2.91
111	5.14	4.52	2.99	48.0	10.6	0.68	0.39	0.82	5.88	2.06	1.23	1.50	1.87	2.87
112	5.51	4.63	2.96	47.9	6.60	0.75	0.39	0.91	6.46	2.25	1.16	1.40	1.84	2.84
113	5.88	4.67	2.90	48.0	4.08	0.82	0.39	1.0	7.05	2.45	1.13	1.34	1.78	2.78
114	6.52	4.85	3.19	43.0	2.16	0.91	0.39	1.2	5.94	1.99	1.11	1.37	1.96	3.06
115	4.75	4.48	3.25	46.3	24.8	0.51	0.36	0.62	3.94	1.38	1.45	1.87	2.11	3.14
116	5.16	4.74	3.31	46.7	17.1	0.56	0.36	0.68	4.50	1.58	1.26	1.58	2.11	3.18
117	5.05	4.45	2.30	62.0	12.6	0.62	0.36	0.68	10.8	3.95	1.20	1.33	1.40	2.19
118	5.88	4.98	3.18	48.4	7.24	0.68	0.36	0.82	6.01	2.10	1.08	1.30	1.97	3.05
119	6.54	5.31	3.71	41.4	4.26	0.75	0.36	1.0	4.57	1.52	1.03	1.32	2.32	3.56
120	6.96	5.30	3.59	41.8	2.54	0.82	0.36	1.1	5.04	1.67	1.02	1.28	2.22	3.44
121	5.07	4.77	3.35	48.5	25.2	0.47	0.33	0.56	4.07	1.44	1.35	1.69	2.15	3.22
122	4.92	4.53	2.47	61.7	20.9	0.51	0.33	0.56	8.58	3.16	1.28	1.44	1.52	3.36

Table 8A. 50-Ohm 5-th Degree Elliptic Highpass Filter Designs Using Standard-Value Capacitors, Capacitive Input and Output.
(Continued from Page 141.)

Filter No.	F-CO	F-3 dB	F-A _S	A _S (dB)	RC (%)	C1	C3	C5	C2	C4	L2	L4	F2	F4
	----- (MHz) -----					----- (nF) -----					--- (μH) ---		--- (MHz) ---	
123	5.99	5.34	3.60	47.1	11.8	0.56	0.33	0.68	4.63	1.62	1.06	1.31	2.27	3.46
124	6.72	5.76	4.15	41.1	7.11	0.62	0.33	0.82	3.74	1.25	0.98	1.27	2.63	3.99
125	6.81	5.48	3.37	49.0	4.58	0.68	0.33	0.82	6.15	2.15	0.96	1.13	2.07	3.22
126	8.07	5.50	3.17	49.3	1.30	0.82	0.33	1.0	7.33	2.54	0.94	1.09	1.91	3.02
127	6.25	5.88	4.61	40.4	21.5	0.43	0.30	0.56	2.45	0.83	1.12	1.55	3.05	4.45
128	5.40	4.95	2.54	64.5	20.2	0.47	0.30	0.51	9.09	3.36	1.15	1.27	1.56	2.43
129	6.10	5.59	3.77	48.8	17.1	0.47	0.30	0.56	4.20	1.48	1.06	1.30	2.39	3.63
130	6.00	5.31	2.77	61.7	13.4	0.51	0.30	0.56	8.73	3.21	1.01	1.13	1.69	2.65
131	7.03	6.00	3.89	47.7	7.64	0.56	0.30	0.68	4.76	1.66	0.91	1.09	2.42	3.73
132	8.08	6.04	3.56	49.7	2.56	0.68	0.30	0.82	6.29	2.19	0.86	1.00	2.16	3.40
133	6.38	5.99	4.26	47.3	23.3	0.39	0.27	0.47	3.18	1.12	1.06	1.34	2.74	4.10
134	6.19	5.63	2.97	62.7	18.4	0.43	0.27	0.47	7.65	2.82	1.00	1.11	1.82	2.84
135	7.34	6.47	4.18	49.2	10.8	0.47	0.27	0.56	4.33	1.53	0.86	1.03	2.61	4.01
136	8.26	7.08	5.13	40.6	6.92	0.51	0.27	0.68	3.00	1.00	0.80	1.04	3.25	4.93
137	8.39	6.73	4.17	48.4	4.41	0.56	0.27	0.68	4.90	1.71	0.78	0.93	2.57	4.00
138	9.30	7.02	4.67	42.7	2.40	0.62	0.27	0.82	3.99	1.33	0.77	0.95	2.87	4.47
139	6.36	5.92	3.08	65.0	24.8	0.36	0.24	0.39	7.06	2.62	1.01	1.12	1.89	2.94
140	8.08	7.52	5.81	40.4	18.1	0.36	0.24	0.47	2.07	0.70	0.84	1.15	3.81	5.61
141	7.94	7.18	4.87	47.7	14.4	0.39	0.24	0.47	3.31	1.16	0.80	0.99	3.08	4.68
142	8.40	7.30	4.62	49.9	9.46	0.43	0.24	0.51	4.10	1.45	0.75	0.89	2.88	4.43
143	8.97	7.44	4.58	49.9	6.06	0.47	0.24	0.56	4.47	1.57	0.71	0.84	2.82	4.38
144	9.94	7.96	5.51	41.6	3.82	0.51	0.24	0.68	3.13	1.04	0.69	0.87	3.43	5.29

Table 88. 600-ohm 5th-Degree Elliptic Highpass-Filter Designs Using Standard-Value Capacitors, Capacitor Input and Output.

Filter No.	F-CO ----- (kHz)	F-3 dB ----- (kHz)	F-A _s ----- (dB)	A _s (dB)	RC (%)	C1	C3	C5 ----- (nF)	C2	C4	L2 --- (mH)	L4 -- (kHz)	F2 -- (kHz)	F4 ---
1	6.60	6.13	4.15	49.6	20.7	33	22	39	305	108	11.9	14.6	2.64	3.99
2	7.67	6.71	4.39	48.1	9.80	39	22	47	340	119	9.88	12.0	2.75	4.21
3	8.70	6.81	4.03	50.5	3.73	47	22	56	456	160	9.17	10.7	2.46	3.85
4	8.40	7.80	5.59	45.9	19.7	27	18	33	207	72.4	9.48	12.1	3.59	5.38
5	9.47	8.13	5.06	50.4	8.50	33	18	39	323	114	7.96	9.42	3.14	4.85
6	10.8	8.39	5.64	49.4	3.42	39	18	47	358	125	7.47	8.74	3.08	4.82
7	11.1	8.76	5.90	42.9	3.42	39	18	51	256	86.0	7.42	9.22	3.65	5.65
8	9.94	9.29	6.75	45.4	21.3	22	15	27	164	57.1	8.13	10.5	4.36	6.50
9	11.5	9.98	6.64	46.8	9.03	27	15	33	220	76.6	6.64	8.13	4.16	6.38
10	12.1	10.6	7.81	40.3	8.59	27	15	36	156	52.0	6.52	8.62	4.99	7.52
11	13.0	9.95	5.71	51.6	3.11	33	15	39	337	119	6.22	7.16	3.47	5.46
12	12.6	11.7	8.38	45.9	19.7	18	12	22	138	48.2	6.32	8.06	5.39	8.07
13	14.6	12.6	8.35	46.6	8.27	22	12	27	177	61.4	5.25	6.43	5.22	8.01
14	16.8	12.7	7.67	48.3	2.69	27	12	33	234	80.9	4.95	5.82	4.68	7.33
15	12.3	11.5	5.48	69.6	25.8	15	10	16	366	137	6.21	6.75	3.34	5.24
16	14.8	13.7	9.57	47.8	20.2	15	10	18	127	44.7	5.35	6.68	6.11	9.21
17	16.0	13.8	7.33	59.5	9.91	18	10	20	276	101	4.58	5.12	4.47	7.01
18	17.2	15.0	9.96	46.8	9.03	18	10	22	147	51.1	4.43	5.42	6.24	9.56
19	18.1	15.9	11.7	40.3	8.59	18	10	24	104	34.7	4.34	5.75	7.49	11.3
20	20.5	16.1	11.2	40.6	3.15	22	10	30	127	42.0	4.10	5.23	6.96	10.7
21	18.5	17.3	12.9	43.7	21.0	12	8.2	15	81.9	28.3	4.39	5.79	8.39	12.4
22	21.0	18.1	11.6	48.7	8.49	15	8.2	18	135	47.3	3.61	4.34	7.21	11.1
23	24.1	18.6	11.4	48.2	3.15	18	8.2	22	155	53.7	3.39	4.00	6.94	10.9
24	24.8	19.4	13.2	41.8	3.18	18	8.2	24	111	37.1	3.37	4.24	8.21	12.7
25	21.4	20.0	14.0	47.8	21.9	10	6.8	12	84.0	29.6	3.75	4.71	8.97	13.5
26	25.4	22.3	15.5	44.7	9.72	12	6.8	15	87.7	30.2	3.03	3.80	9.76	14.8
27	29.0	22.2	13.1	49.9	3.06	15	6.8	18	141	49.4	2.82	3.28	7.98	12.5
28	26.4	24.7	17.8	46.1	21.7	8.2	5.6	10	63.1	22.1	3.06	3.92	11.5	17.1
29	30.2	26.3	17.0	48.6	9.51	10	5.6	12	89.3	31.4	2.51	3.02	10.6	16.4
30	34.9	27.5	17.6	46.1	3.64	12	5.6	15	93.0	31.9	2.32	2.80	10.8	16.8
31	30.6	28.7	20.4	47.2	23.2	6.8	4.7	8.2	55.3	19.5	2.65	3.36	13.2	19.7
32	35.8	31.6	21.2	46.9	10.4	8.2	4.7	10	66.9	23.3	2.13	2.61	13.3	20.4
33	40.7	32.0	19.2	49.7	3.81	10	4.7	12	93.4	32.7	1.96	2.29	11.8	18.4
34	49.0	32.5	19.2	47.4	1.05	12	4.7	15	97.1	33.2	1.94	2.27	11.6	18.3
35	37.0	34.8	25.1	46.5	23.6	5.6	3.9	6.8	43.7	15.3	2.21	2.83	16.2	24.2
36	42.8	37.7	24.9	48.0	10.6	6.8	3.9	8.2	58.8	20.6	1.77	2.16	15.6	23.9
37	49.0	39.0	24.2	48.0	4.08	8.2	3.9	10	70.5	24.5	1.63	1.93	14.9	23.2
38	42.2	39.8	27.9	48.5	25.2	4.7	3.3	5.6	40.7	14.4	1.94	2.43	17.9	26.9
39	49.9	44.5	30.0	47.1	11.8	5.6	3.3	6.8	46.3	16.2	1.53	1.88	18.9	28.8
40	56.7	45.7	28.1	49.0	4.58	6.8	3.3	8.2	61.5	21.5	1.38	1.63	17.3	26.9
41	67.3	45.8	26.4	49.3	1.30	8.2	3.3	10	73.3	25.4	1.36	1.57	15.9	25.2
42	53.2	49.9	35.5	47.3	23.3	3.9	2.7	4.7	31.8	11.2	1.53	1.94	22.8	34.2
43	61.2	53.9	34.8	49.2	10.8	4.7	2.7	5.6	43.3	15.3	1.23	1.48	21.8	33.4
44	69.9	56.1	34.8	48.4	4.41	5.6	2.7	6.8	49.0	17.1	1.13	1.34	21.4	33.3

FILTER CHARACTERISTICS AND DESIGN FORMULAS

Band-Pass Sections

Fundamental Relations



















R = load resistance f_1 = lower frequency limit of pass band f_2 = higher frequency limit of pass band

f_{∞} = a frequency of very high attenuation in low-frequency attenuating band
 f_{∞} = a frequency of very high attenuation in high-frequency attenuating band

$$L_{1k} = \frac{R}{\pi(f_2 - f_1)} \quad L_{2k} = \frac{4\pi f_1 f_2}{(f_2^2 - f_1^2)} \quad C_{1k} = \frac{f_2 - f_1}{4\pi f_1 f_2 R} \quad C_{2k} = \frac{1}{\pi(f_2 - f_1)R}$$

Design of Sections

Type	Attenuation characteristic	A. Filter having π intermediate sections	B. Filter having ϵ intermediate sections	Notation for both T and ϵ sections
<div> $\frac{R_{\infty}}{R_{\infty}}$ (as approx. unity 0.0) </div>	<p>Frequency</p>	<p>Intermediate sections</p> $L_1 = m\omega_0 C_1$ $L_2 = \frac{m}{\omega_0 C_1}$ $L_1' = \frac{m}{\omega_0 C_1}$ $C_2 = \frac{1}{m\omega_0 C_1}$	$L_1 = \frac{L_0}{b}$ $L_2 = \frac{L_0}{a}$ $C_1 = \frac{a}{m\omega_0 C_0}$ $C_2 = \frac{m}{\omega_0 C_0}$	$\rho = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right)\left(1 - \frac{f_1^2}{f_2^2}\right)}$ $h = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right)\left(1 - \frac{f_1^2}{f_2^2}\right)}$ $m = \frac{1}{\frac{f_1}{f_2} + h}$ $a = \frac{4\pi f_1 f_2}{(1 - m^2)^2} \left(1 - \frac{f_1^2}{f_2^2}\right)$ $b = \frac{4\pi f_1 f_2}{(1 - m^2)^2} \left(1 - \frac{f_1^2}{f_2^2}\right)$ $d = \frac{(1 - m^2)^2 f_1 f_2}{4\pi h (1 - m^2)}$ <p>when $(m = m_0)$,</p> $\rho = h, a = d, b = c, f_{\infty} = \frac{f_1 f_2}{f_{\infty}}$ $m_1 = m_2 = \frac{1}{f_{\infty}}$ <p>and</p> $f_{\infty} = \frac{\sqrt{(1 + f_2^2 - 2m^2 f_1 f_2)} + \left[\frac{(1 + f_2^2 - 2m^2 f_1 f_2)}{2(1 - m^2)}\right] - f_1 f_2}{2(1 - m^2)}$ <p>These formulas apply for both end and Type I sections</p>
I	<p>Frequency</p>	$L_1 = m\omega_0 C_1$ $L_2 = \frac{m}{\omega_0 C_1}$ $L_1' = \frac{m}{\omega_0 C_1}$ $C_2 = \frac{1}{m\omega_0 C_1}$	$L_1 = \frac{L_0}{b}$ $L_2 = \frac{L_0}{a}$ $C_1 = \frac{a}{m\omega_0 C_0}$ $C_2 = \frac{m}{\omega_0 C_0}$	$\rho = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right)\left(1 - \frac{f_1^2}{f_2^2}\right)}$ $h = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right)\left(1 - \frac{f_1^2}{f_2^2}\right)}$ $m = \frac{1}{\frac{f_1}{f_2} + h}$ $a = \frac{4\pi f_1 f_2}{(1 - m^2)^2} \left(1 - \frac{f_1^2}{f_2^2}\right)$ $b = \frac{4\pi f_1 f_2}{(1 - m^2)^2} \left(1 - \frac{f_1^2}{f_2^2}\right)$ $d = \frac{(1 - m^2)^2 f_1 f_2}{4\pi h (1 - m^2)}$ <p>when $(m = m_0)$,</p> $\rho = h, a = d, b = c, f_{\infty} = \frac{f_1 f_2}{f_{\infty}}$ $m_1 = m_2 = \frac{1}{f_{\infty}}$ <p>and</p> $f_{\infty} = \frac{\sqrt{(1 + f_2^2 - 2m^2 f_1 f_2)} + \left[\frac{(1 + f_2^2 - 2m^2 f_1 f_2)}{2(1 - m^2)}\right] - f_1 f_2}{2(1 - m^2)}$ <p>These formulas apply for both end and Type I sections</p>
II	<p>Frequency</p>	$L_1 = m\omega_0 C_1$ $L_2 = \frac{m}{\omega_0 C_1}$ $L_1' = \frac{m}{\omega_0 C_1}$ $C_2 = \frac{1}{m\omega_0 C_1}$	$L_1 = \frac{L_0}{b}$ $L_2 = \frac{L_0}{a}$ $C_1 = \frac{a}{m\omega_0 C_0}$ $C_2 = \frac{m}{\omega_0 C_0}$	$\rho = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right)\left(1 - \frac{f_1^2}{f_2^2}\right)}$ $h = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right)\left(1 - \frac{f_1^2}{f_2^2}\right)}$ $m = \frac{1}{\frac{f_1}{f_2} + h}$ $a = \frac{4\pi f_1 f_2}{(1 - m^2)^2} \left(1 - \frac{f_1^2}{f_2^2}\right)$ $b = \frac{4\pi f_1 f_2}{(1 - m^2)^2} \left(1 - \frac{f_1^2}{f_2^2}\right)$ $d = \frac{(1 - m^2)^2 f_1 f_2}{4\pi h (1 - m^2)}$ <p>when $(m = m_0)$,</p> $\rho = h, a = d, b = c, f_{\infty} = \frac{f_1 f_2}{f_{\infty}}$ $m_1 = m_2 = \frac{1}{f_{\infty}}$ <p>and</p> $f_{\infty} = \frac{\sqrt{(1 + f_2^2 - 2m^2 f_1 f_2)} + \left[\frac{(1 + f_2^2 - 2m^2 f_1 f_2)}{2(1 - m^2)}\right] - f_1 f_2}{2(1 - m^2)}$ <p>These formulas apply for both end and Type I sections</p>

III $f_{\infty} = f_1$ $f_{\infty} = \infty$			$L_1 = Z_{ab}$ $C_1' = \frac{1}{\omega f_1 Z_{ab}}$ $C_1 = \frac{1}{\omega f_1 Z_{ab}}$		$L_1' = \frac{Z_{ab}}{\omega f_1}$ $L_1 = \frac{Z_{ab}}{\omega f_1}$ $C_1 = C_{ab}$	$L_1' = \frac{R}{\omega f_1}$ $L_1 = \frac{R}{\omega f_1}$ $C_1 = C_{ab}$	
IV $f_{\infty} = 0$ $f_{\infty} = \infty$			$L_1 = Z_{ab}$ $C_1' = \frac{1}{\omega f_1 Z_{ab}}$ $C_1 = \frac{1}{\omega f_1 Z_{ab}}$		$L_1' = \frac{Z_{ab}}{\omega f_1}$ $L_1 = \frac{Z_{ab}}{\omega f_1}$ $C_1 = C_{ab}$	$L_1' = \frac{Z_{ab}}{\omega f_1}$ $L_1 = \frac{Z_{ab}}{\omega f_1}$ $C_1 = C_{ab}$	
V $f_{\infty} = f_1$			$L_1 = m L_{ab}$ $L_1 = \frac{(1 - m^2) L_{ab}}{\omega f_1}$ $C_1 = \frac{m}{\omega f_1 Z_{ab}}$ $C_1 = \frac{1}{\omega f_1 Z_{ab}}$ See notation for m_1 and m_2		$L_1' = \frac{L_{ab}}{\omega f_1}$ $L_1 = \frac{L_{ab}}{\omega f_1}$ $C_1 = \frac{m}{\omega f_1 Z_{ab}}$ $C_1 = \frac{1}{\omega f_1 Z_{ab}}$ See notation for m_1 and m_2	$m_1 = \frac{f_1}{f_2}$ $m_2 = \sqrt{\frac{1 - \frac{f_1^2}{f_2^2}}{1 - \frac{f_1^2}{f_2^2}}}$	
VI $f_{\infty} = f_1$			Same formulae as above for Type V. See notation for m_1 and m_2		Same formulae as above for Type V. See notation for m_1 and m_2	$m_1 = \frac{f_1}{f_2}$ $m_2 = \sqrt{\frac{1 - \frac{f_1^2}{f_2^2}}{1 - \frac{f_1^2}{f_2^2}}}$	
VII $f_{\infty} = 0$			$L_1 = m L_{ab}$ $L_1 = \frac{(1 - m^2) L_{ab}}{\omega f_1}$ $C_1 = \frac{m}{\omega f_1 Z_{ab}}$ $C_1' = \frac{1}{\omega f_1 Z_{ab}}$		$L_1' = \frac{L_{ab}}{\omega f_1}$ $L_1 = \frac{L_{ab}}{\omega f_1}$ $C_1 = \frac{m}{\omega f_1 Z_{ab}}$ $C_1' = \frac{1}{\omega f_1 Z_{ab}}$	$h = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right) \left(1 - \frac{f_1^2}{f_2^2}\right)}$ $m_1 = \frac{f_1^2}{f_2^2} + h$ $a = \frac{1 - m_1^2}{h}$	
VIII $f_{\infty} = \infty$			$L_1 = Z_{ab}$ $L_1 = \frac{Z_{ab}}{\omega f_1}$ $C_1 = \frac{1}{\omega f_1 Z_{ab}}$ $C_1' = \frac{1}{\omega f_1 Z_{ab}}$		$L_1' = \frac{Z_{ab}}{\omega f_1}$ $L_1 = \frac{Z_{ab}}{\omega f_1}$ $C_1 = \frac{1}{\omega f_1 Z_{ab}}$ $C_1' = \frac{1}{\omega f_1 Z_{ab}}$	$r = \sqrt{\left(1 - \frac{f_1^2}{f_2^2}\right) \left(1 - \frac{f_1^2}{f_2^2}\right)}$ $m_1 = a + \frac{1}{h}$ $d = \frac{1 - m_1^2}{h}$	

(From *Radio Engineers' Handbook* by F. E. Terman. Copyright © 1943 by McGraw-Hill Book Company, Inc. Used with permission of McGraw-Hill Book Company.)

COMB-FILTER DESIGN

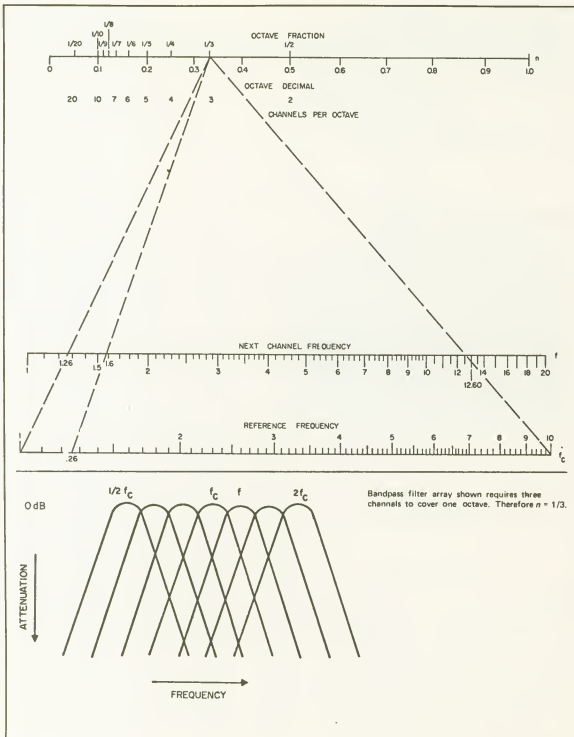
Comb filters consist of a chain of narrow-band filters which pass spectral lines over the frequency spectrum of the signal. They pass discrete frequency components and discriminate against noise. Such filters are used to separate a composite input signal into a number of channels before data processing in telemetry systems and radar. The spacing between channels may be expressed as a frequency ratio which depends on the number of channels needed to cover one octave, or " n ." Thus $f/f_c = 2^n$, where f_c is the reference, f is the unknown frequency of the adjacent channel, and n is any positive or negative real number. For $n = \pm 1$, f equals $2f_c$ and $\frac{1}{2}f_c$. These values are the center frequencies of channels, one octave away from the reference frequency.

The nomogram solves for positive or negative fractional values of n . The frequency scales, f_c and f , are normalized so that the nomogram can be used for any frequency by shifting the decimal point. The ratio scale, n , has a decimal range as well as fractional values.

To use the nomogram, place a straight-edge from the octave fraction or decimal on the n scale to the reference frequency on the f_c scale. Read the center frequency of the next channel on the f scale. Hold the n -scale value as a pivot point and shift the straight-edge to the same frequency on the f_c scale as the first answer. Read the next bandpass center frequency on the f scale. Continue the process until all center frequencies are obtained. For negative n values, divide the reference frequency by two to obtain the lower octave. After this step, proceed as for a positive n value.

FOR EXAMPLE: Calculate the center frequencies for 1/3 octave filters, starting at 100 Hz (see illustration).

Set the straight-edge from 1/3 or 0.33 on the n scale to the one (for 100 Hz) on the f_c scale and read 1.26 on the f scale; the center frequency of the next channel bandpass filter is 126 Hz. Pivot at 1/3 on the n scale and shift the straightedge to 126 on the f_c scale. Read 160 Hz on the f scale. When 1,260 Hz on the f scale and 1,000 Hz on f_c is reached, shift back to the lower portion of the f_c scale and continue.



PULSE-FORMING NETWORK NOMOGRAM

Pulse-forming networks supply high-voltage pulses to magnetrons and lasers. This nomogram relates the pulse width and characteristic impedance to the network's inductances and capacitances. It is based on the formulas:

$$Z_o = \sqrt{\frac{L}{C}}; P_w = 2n \sqrt{LC}$$

$$n = \frac{P_w}{2r}$$

where Z_o = characteristic impedance

L = inductance per section

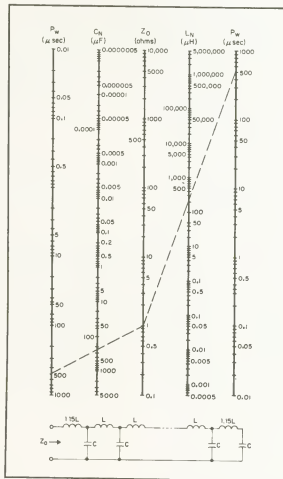
C = capacitance per section

n = number of sections

P_w = pulse width

r = rise time

FOR EXAMPLE: Design a PFN that delivers a 4-kV, 500- μ sec pulse with a 25- μ sec rise time into a 1-ohm load: The numbers of sections ($P_w/2r$) is 10. Connecting 1 ohm to 500 μ sec on the left and right scales yields 250 μ F and 250 μ H as total capacitive C_N and total inductance L_N . Dividing by 10 gives 25 μ F and 25 μ H per section. The two end inductances are 1.15 the value of each section or 2.875 μ H.



DELAY LINE DESIGN NOMOGRAM

A pulse applied to the input of a delay line is continuously delayed by a predetermined amount as it travels along the line. The artificial or lumped parameter type of delay line consists of a series of low pass LC filters. The delay for n sections is given by the formula

$$t = n \sqrt{LC}$$

where t = time delay in microseconds

L = inductance in microhenries

n = number of sections

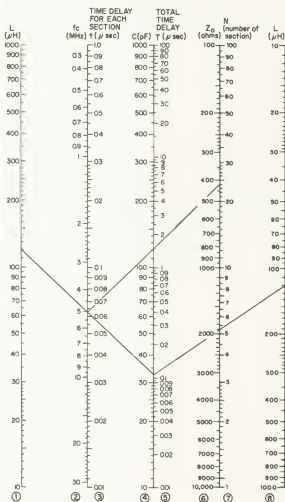
C = capacitance in microfarad

The characteristic impedance Z_0 must be matched to reduce reflections within the delay line and is given by the formula

$$Z_0 = \sqrt{L/C}$$

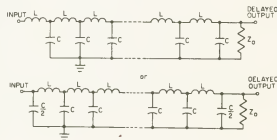
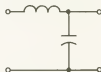
where Z_0 is in ohms

The cutoff frequency of each section must be higher than the operating frequency $f_c = \frac{1}{\pi \sqrt{LC}}$
where f_c is the cutoff frequency in megahertz



FOR EXAMPLE: Determine the parameters for a delay line with a $1.5\text{-}\mu\text{sec}$ delay and an f_o of 5 MHz. Pivot around 5 MHz on scale 2 and select standard values of L and C on scales 1 and 4. ($120\text{ }\mu\text{H}$ and 33 pF) The cutoff frequency on scale 2 corresponds to the time delay per section shown on scale 3—in this case $0.063\text{ }\mu\text{sec/section}$. The time delay per section aligned with the required total delay ($1.5\text{ }\mu\text{sec}$) on scale 5 shows the total number of sections required as 24 on scale 7. The characteristic impedance of the line is found to be $1,900\text{ ohms}$ as shown on scale 6 by aligning C (33 pF) on scale 5, with the previously selected value of L ($120\text{ }\mu\text{H}$) on scale 8.

SINGLE SECTION



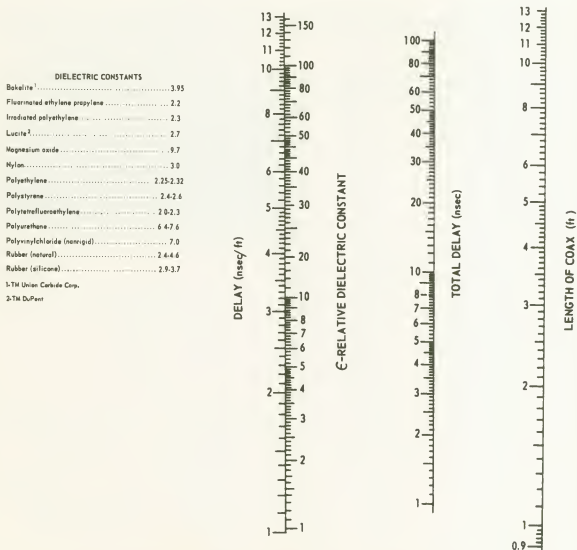
COAXIAL CABLE SIGNAL DELAY NOMOGRAM

This nomogram solves for the delay per foot as well as the total delay of a coaxial cable when the relative dielectric constant of the insulation is known. The nomogram is based on the relationship

$$T = 1.108 \sqrt{E} \text{ nsec/ft}$$

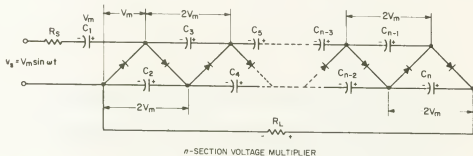
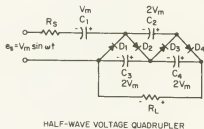
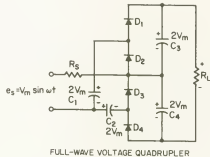
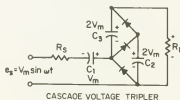
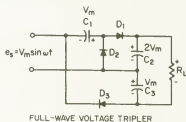
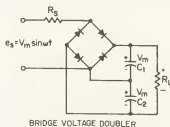
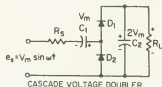
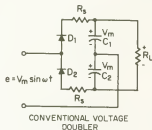
The relative dielectric constant and delay per foot are plotted on the left-hand index and can be related directly. The chart gives the approximate ranges of dielectric constants of commonly used insulating materials. Some dielectric properties are a function of composition, frequency, and temperature, and the values shown should be used accordingly.

FOR EXAMPLE: A 4-ft cable with a polystyrene dielectric will produce a total delay of about 6.3 to 6.5 nsec.



VOLTAGE MULTIPLIER CIRCUITS

Circuit diagrams are given and the minimum voltage ratings of the capacitors are shown as related to V_m . The minimum PIV of the diodes is $2V_m$.



POWER TRANSISTOR AND DIODE REQUIREMENTS FOR SWITCHING POWER SUPPLIES

This tabulation shows the transfer function, switching transistor currents and voltages, diode currents and voltages as well as voltage and current waveforms for ten different converter circuit configurations used in switching power supplies.

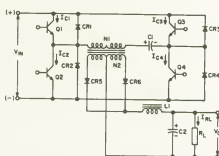
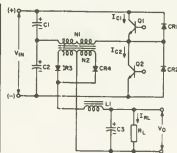
The advantages and disadvantages of each circuit configuration are also given.

CIRCUIT CONFIGURATION			
TYPE OF CONVERTER	BUCK (STEP DOWN)	BOOST (STEP UP)	BUCK-BOOST
IDEAL TRANSFER FUNCTION	$\frac{V_0}{V_{IN}} = \frac{T}{T-\gamma} < 1$	$\frac{V_0}{V_{IN}} = \frac{T}{T-\gamma} > 1$	$\frac{V_0}{V_{IN}} = \left(\frac{T}{T-\gamma}\right)(1-\gamma)$
COLLECTOR CURRENT (I_C)	$I_C \text{ MAX} = I_{RL} + \Delta I_{L1} / 2$	$I_C \text{ MAX} = I_{RL} \left(\frac{T}{T-\gamma}\right) + \frac{\Delta I_{L1}}{2}$	$I_C \text{ MAX} = I_{RL} \left(\frac{T}{T-\gamma}\right) + \frac{\Delta I_{L1}}{2}$
COLLECTOR VOLTAGE RATING	$V_{CEO} = V_{IN}$	$V_{CEO} > V_0 + I$	$V_{CEO} > V_{IN} + V_0$
DIODE CURRENTS	$I_{CR1} = I_{RL} \left(\frac{T-\gamma}{T}\right)$	$I_{CR1} = I_{RL}$	$I_{CR1} = I_{RL}$
DIODE VOLTAGES (V_{RM})	$V_{RM} = V_{IN}$	$V_{RM} = V_0$	$V_{RM} = V_0 + V_{IN}$
VOLTAGE AND CURRENT WAVEFORMS			
ADVANTAGES	HIGH EFFICIENCY, SIMPLE, NO TRANSFORMER, HIGH FREQUENCY OPERATION, EASY TO STABILIZE REGULATOR LOOP	HIGH EFFICIENCY, SIMPLE, NO TRANSFORMER, HIGH FREQUENCY OPERATION	VOLTAGE INVERSION WITHOUT USING A TRANSFORMER, SIMPLE, HIGH FREQUENCY OPERATION
DISADVANTAGES	NO ISOLATION BETWEEN INPUT AND OUTPUT, REQUIRES A CROWBAR IF Q1 SHORTS, Q1 HAS HIGH RIPPLE CURRENT, CURRENT LIMIT DIFFICULT, ONLY ONE OUTPUT IS POSSIBLE	NO ISOLATION BETWEEN INPUT AND OUTPUT, HIGH PEAK COLLECTOR CURRENT, ONLY ONE OUTPUT IS POSSIBLE, POOR TRANSIENT RESPONSE, REGULATOR LOOP HARD TO STABILIZE	Q1 MUST CARRY HIGH PEAK CURRENT, NO ISOLATION BETWEEN INPUT AND OUTPUT, ONLY ONE OUTPUT IS POSSIBLE, POOR TRANSIENT RESPONSE
* = FOR RELIABLE OPERATION, IT IS SUGGESTED AND RECOMMENDED THAT ALL VOLTAGE			

<p style="text-align: center;">① FLYBACK</p> $V_O = \frac{N_2}{N_1} \left(\frac{V}{T - \tau} \right)$ $I_{C \text{ MAX}} = I_{RL} \frac{N_2}{N_1} \left(\frac{T}{T - \tau} \right) + \frac{\Delta I_{LL}}{2}$ $V_{CEO} > V_{IN} + \left(\frac{N_1}{N_2} \right) V_{OUT}$ $I_{CR1} = I_{RL}$ $V_{RM} = V_{IN} \left(\frac{N_2}{N_1} \right)$	<p style="text-align: center;">② FORWARD ✓</p> $V_O = \frac{N_2}{N_1} \left(\frac{I}{T} \right)$ $I_{C \text{ MAX}} = I_{RL} \left(\frac{N_2}{N_1} \right) + \frac{\Delta I_{LL}}{2} + \frac{I_{MAG}}{2}$ $V_{CEO} > V_{IN} \left(1 + \frac{N_1}{N_2} \right)$ $I_{CR1} = \frac{I_{MAG}}{2} \left(\frac{T}{T} \right)$ $I_{CR2} = I_{RL} \left(\frac{T}{T} \right)$ $I_{CR3} = I_{RL} \left(\frac{T - \tau}{T} \right)$ $\left. \begin{aligned} V_{CR1} &= V_{IN} \left(1 + \frac{N_1}{N_2} \right) \\ V_{CR2} &= V_{IN} \left(\frac{N_2}{N_1} \right) \\ V_{CR3} &= V_{IN} \left(\frac{N_2}{N_1} \right) \end{aligned} \right\} V_{RM}$
<p>SIMPLE, MULTIPLE OUTPUTS ARE POSSIBLE. COLLECTOR CURRENT REDUCED BY TURNS RATIO OF TRANSFORMER. LOW PARTS COUNT, ISOLATION</p> <p>POOR TRANSFORMER UTILIZATION, TRANSFORMER DESIGN CRITICAL, HIGH OUTPUT RIPPLE</p>	<p>SIMPLE, MULTIPLE OUTPUTS ARE POSSIBLE, COLLECTOR CURRENT REDUCED BY RATIO OF $\frac{N_2}{N_1}$. LOW OUTPUT RIPPLE</p> <p>POOR TRANSFORMER UTILIZATION, POOR TRANSIENT RESPONSE, PARTS COUNT HIGH, TRANSFORMER DESIGN IS CRITICAL</p>

AND CURRENT RATINGS BE INCREASED TO 125% OF THE REQUIRED MAXIMUM.

CIRCUIT CONFIGURATION



TYPE OF CONVERTER

②

HALF BRIDGE

③

FULL BRIDGE

IDEAL TRANSFER FUNCTION

$$\frac{V_O}{V_{IN}} = \frac{N_2}{N_1} \left(\frac{T}{T} \right)$$

$$\frac{V_O}{V_{IN}} = 2 \frac{N_2}{N_1} \left(\frac{T}{T} \right)$$

COLLECTOR CURRENT (I_C)

$$I_{C \text{ MAX}} = \frac{N_2}{N_1} \left(I_{RL} + \frac{\Delta I_{L1}}{2} \right) + \frac{I_{MAG}}{2}$$

$$I_{C \text{ MAX}} = \frac{N_2}{N_1} \left(I_{RL} + \frac{\Delta I_{L1}}{2} \right) + \frac{I_{MAG}}{2}$$

COLLECTOR VOLTAGE RATING

$$V_{CEO} = V_{IN}$$

$$V_{CEO} = V_{IN}$$

DIODE CURRENTS

$$I_{CR3} = \frac{I_{RL}}{2}$$

$$I_{CR4} = \frac{I_{RL}}{2}$$

$$I_{CR5} = I_{RL}$$

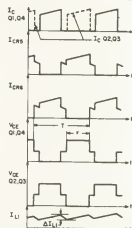
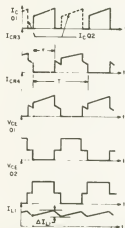
$$I_{CR6} = I_{RL}$$

DIODE VOLTAGES (V_{RM})

$$V_{RM} = \begin{cases} V_{CR3} = V_{IN} \left(\frac{N_2}{N_1} \right) \\ V_{CR4} = V_{IN} \left(\frac{N_2}{N_1} \right) \end{cases}$$

$$V_{RM} = \begin{cases} V_{CR5} = 2 V_{IN} \left(\frac{N_2}{N_1} \right) \\ V_{CR6} = 2 V_{IN} \left(\frac{N_2}{N_1} \right) \end{cases}$$

VOLTAGE AND CURRENT WAVEFORMS



ADVANTAGES

SIMPLE, GOOD TRANSFORMER UTILIZATION, TRANSISTORS RATED AT V_{IN} ISOLATION, MULTIPLE OUTPUTS, I_C REDUCED AS A RATIO OF $\frac{N_2}{N_1}$ HIGH POWER OUTPUT

SIMPLE, GOOD TRANSFORMER UTILIZATION, TRANSISTORS RATED AT V_{IN} ISOLATION, MULTIPLE OUTPUTS, I_C REDUCED AS A RATIO OF $\frac{N_2}{N_1}$ HIGH POWER OUTPUT PREFERRED TO CKT ② WHERE HIGH POWER REQUIRED.

DISADVANTAGES

POOR TRANSIENT RESPONSE, HIGH PARTS COUNT, C1 AND C2 HAVE HIGH RIPPLE CURRENT, LIMITED DYNAMIC RANGE, REQUIRES AUXILIARY POWER SUPPLIES FOR CONTROL CIRCUITS

POOR TRANSIENT RESPONSE, HIGH PARTS COUNT, C1 AND C2 HAVE HIGH RIPPLE CURRENT, LIMITED DYNAMIC RANGE, REQUIRES AUXILIARY POWER SUPPLIES FOR CONTROL CIRCUIT

* FOR RELIABLE OPERATION, IT IS SUGGESTED AND RECOMMENDED THAT ALL VOLTAGE AND CURRENT RATINGS BE INCREASED TO 125% OF THE REQUIRED MAXIMUM.

<p>① PUSH-PULL</p>	<p>② BUCK (BOOST - BUCK INVERTING)</p>	<p>③ BUCK (WITH TRANSFORMER)</p>
$\frac{V_0}{V_{IN}} = 2 \frac{N_2}{N_1} \left(\frac{1}{1} \right)$	$\frac{V_0}{V_{IN}} = \left(\frac{1}{1-x} \right) (1-x)$	$\frac{V_0}{V_{IN}} = \frac{x}{1-x}, 0 < \frac{x}{1-x} \leq 1$
$I_{C \text{ MAX}} = \frac{N_2}{N_1} \left(I_{RL} + \frac{\Delta I_{L1}}{2} \right) + \frac{1}{2} I_{MAG}$	$I_{C \text{ MAX}} = I_1 + I_2 = I_1 \left(\frac{1}{1-x} \right)$	$I_{C1} = 1.5 I_{RL} \text{ FOR } D = 0.33 \text{ (} V_0 = 0.5 V_{IN} \text{)}$ $I_{C2} = 2 I_{RL} \text{ FOR } D = 0.50 \text{ (} V_0 = V_{IN} \text{)}$ $I_{C3} = 2.5 I_{RL} \text{ FOR } D = 0.60 \text{ (} V_0 = 1.5 V_{IN} \text{)}$
$V_{CE0} \geq 2 V_{IN}$	$V_{CE0} \geq 2 V_{IN}$	$V_{CE0} = \frac{1.5 V_{IN}}{0.33}, \frac{2 V_{IN}}{0.5}, \frac{2.5 V_{IN}}{0.6}$
$I_{CR1} = \frac{I_{RL}}{2}$ $I_{CR2} = \frac{I_{RL}}{2}$	$I_{CR1} = I_1 + I_2$ $I_1 + I_2 = I_1 \left(\frac{1}{1-x} \right)$	$I_{CR1} = 1.5 I_{RL} \text{ FOR } D = 0.33$ $I_{CR1} = 2 I_{RL} \text{ FOR } D = 0.50$ $I_{CR1} = 2.5 I_{RL} \text{ FOR } D = 0.60$
$V_{RM} = \begin{cases} V_{CR1} = 2 V_{IN} \left(\frac{N_2}{N_1} \right) \\ V_{CR2} = 2 V_{IN} \left(\frac{N_2}{N_1} \right) \end{cases}$	$V_0 = 1$	$1.5 V_{IN} \text{ FOR } D = 0.33$ $2 V_{IN} \text{ FOR } D = 0.50$ $2.5 V_{IN} \text{ FOR } D = 0.60$
<p>SIMPLE, GOOD TRANSFORMER UTILIZATION. COLLECTOR CURRENT REQUIRED AS A FUNCTION OF $\frac{N_2}{N_1}$ GOOD AT LOW VALUES OF V_{IN}.</p>	<p>CONTINUOUS INPUT AND OUTPUT CURRENT, HIGHEST EFFICIENCY, LOW RIPPLE, SMALLEST NUMBER OF SWITCHING COMPONENTS, SWITCHING LOSSES CUT IN HALF, DRIVE CIRCUIT REFERENCED TO GROUND, HIGHEST OPERATING FREQUENCY.</p>	<p>CONTINUOUS INPUT AND OUTPUT CURRENT, HIGHEST EFFICIENCY, VERY LOW RIPPLE, SMALLEST NUMBER OF SWITCHING COMPONENTS, SWITCHING LOSSES LOW, DRIVE CURRENT REFERENCED TO GROUND, HIGHEST OPERATING FREQUENCY.</p>
<p>CROSS CONDUCTION OF Q1 OR POSSIBLY HIGH PARTS COUNT. TRANSFORMER DESIGN CRITICAL. POOR DYNAMIC RANGE. POOR TRANSIENT RESPONSE.</p>	<p>HIGH COLLECTOR CURRENT Q1 HAS HIGH RIPPLE CURRENT REQUIREMENT. HIGH VOLTAGE REQUIRED FOR Q1. POWER OUTPUT LIMITED.</p>	<p>Q1 AND C2 HAVE HIGH RIPPLE CURRENT REQUIREMENTS. TRANSFORMER DESIGN CRITICAL. POWER OUTPUT IS LIMITED.</p>

(From General Electric Application Note 200.87, "Power Transistor Applications for Switching Regulators and Motor Control," copyrighted © by and reprinted with permission of General Electric Company.)

PERCENT REGULATION OF POWER SUPPLIES

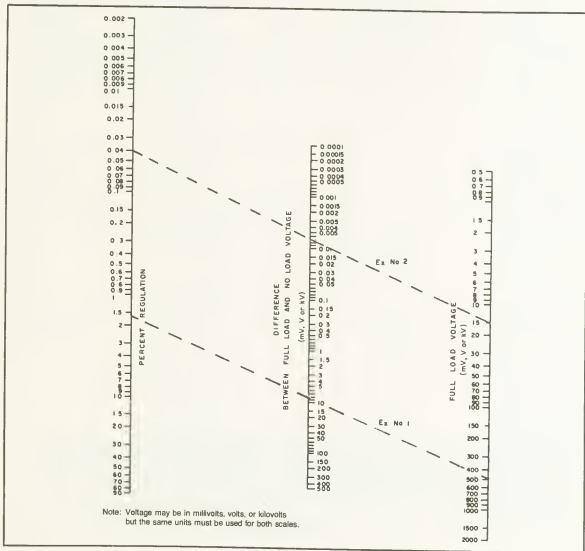
The percent regulation of a power supply is found by the change in output voltage between *Full Load* and *No Load* voltage as given by the formula:

$$\% \text{ regulation} = \frac{\text{No Load Voltage} - \text{Full Load Voltage}}{\text{Full Load Voltage}} \times 100.$$

FOR EXAMPLE:

1. What is percent regulation if *No Load Voltage* is 500 V and *Full Load Voltage* is 492 V? The difference is 8 V. **Answer:** Connecting 492 and 8 gives a regulation of about 1.6%.

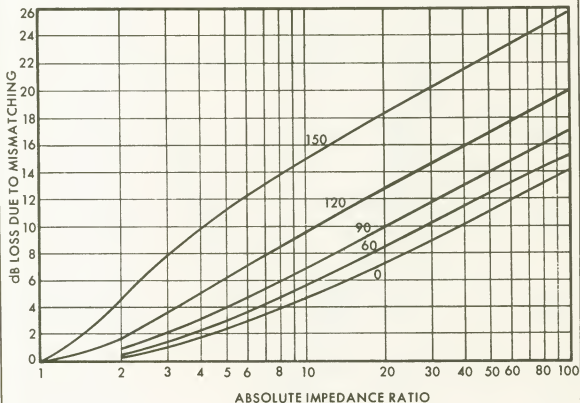
2. For 0.04% regulation what is maximum allowable change in output voltage if required *Full Load Voltage* is 15 V. **Answer:** 0.006 V.



POWER LOSS DUE TO IMPEDANCE MISMATCH

This chart shows the power loss resulting from inequality in the absolute magnitude of two impedances connected so as to transfer power from one to the other. The figures on the curves are the number of degrees of algebraic phase difference between the two impedances.

FOR EXAMPLE: Find the resulting power loss when a loudspeaker with an impedance of 10 ohms and a phase angle of 60° is fed from a generator with a 100-ohm internal impedance. The impedance mismatch ratio is 10:1, and at the 60° line the loss due to mismatch is read as 5.7 dB.



SEVEN COMMONLY USED BRIDGE CIRCUITS AND THEIR BALANCE EQUATIONS

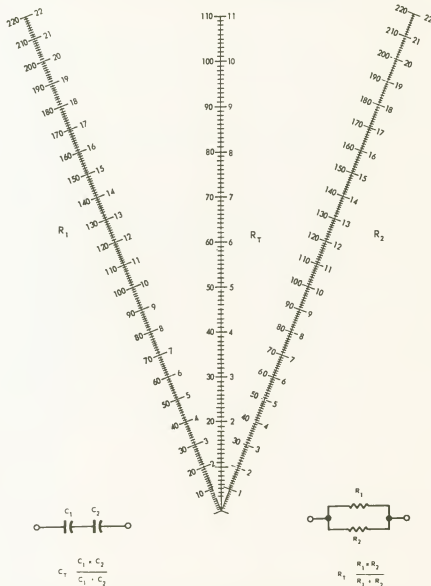
A bridge consists essentially of four arms connected in series and so arranged, that when an electromotive force is applied across one pair of opposite junctions, the response of a detecting and /or indicating device connected between the other pair of junctions may be zeroed by adjusting one or more of the elements of the arms of the bridge. Seven commonly used bridge circuits and their balance equations are shown.

			Principally Used to Measure
WHEATSTONE BRIDGE		$R_d = \frac{R_a R_c}{R_b}$	Resistance
WIEN BRIDGE		$\omega^2 = \frac{1}{R_d R_c C_d C_c} \text{ and } \frac{C_d R_b}{C_c} = \frac{R_c}{R_d}$ or $C_d^2 = \frac{R_b R_d - R_a R_c}{R_a R_d^2 R_c \omega^2} \text{ and } C_c^2 = \frac{R_a}{(R_b R_d - R_a R_c) R_c \omega^2}$	Capacitance—Frequency
RESONANCE BRIDGE		$\omega L = \frac{1}{\omega C}$ $R_d = \frac{R_a R_c}{R_b}$	Inductance
MAXWELL BRIDGE		$L_d = R_a R_c C_b$ $R_d = \frac{R_a R_c}{R_b}$	Inductance
SCHERING BRIDGE		$C_d = \frac{R_b}{R_a} C_c$ $R_d = \frac{C_b}{C_c} R_a$	Capacitance—Inductance
OWEN BRIDGE		$L_d = R_a R_c C_b$ $R_d = \frac{C_b}{C_a} R_c$	Inductance
HAY BRIDGE		$L = \frac{R_a R_c C_b}{1 + (R_b \omega C_b)^2}$ $R_d = \frac{R_a R_b R_c (\omega C_b)^2}{1 + (R_b \omega C_b)^2}$	Inductance

PARALLEL-RESISTOR/SERIES-CAPACITOR NOMOGRAM

This nomogram is used to find the effective resistance of resistors connected in parallel or the capacitance of capacitors connected in series. The range of the nomogram may be extended by multiplying the three scales by the same factor 10^n , where n may be positive or negative.

FOR EXAMPLE: (1) The effective resistance of a 150k and 120k resistor in parallel is 67k. (2) A 6.8 μ f and 5.6 μ f capacitor connected in series present an effective capacitance of 3 μ F.


















(From "Parallel-Resistance Chart," *EDN*, September 14, 1966 by permission of *EDN*.)

Section 4

Active Components and Circuits

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MAJOR SEMICONDUCTOR COMPONENTS

NAME OF DEVICE	CIRCUIT SYMBOL	COMMONLY USED JUNCTION SCHEMATIC	ELECTRICAL CHARACTERISTICS	MAJOR APPLICATIONS	ROUGHLY ANALOGOUS TO
Diode or Rectifier				Rectification Blocking Detecting Steering	Check valve Diode tube Gas diode
Avalanche (Zener) Diode				Regulation Reference Clipping	V-R tube
Integrated Voltage Regulator (ICVR)				Shunt voltage regulator Reference element Error modifier Level sensing Level shifting	Avalanche Diode
Tunnel Diode				UHF converter Logic circuits Microwave circuits Level sensing	None
Back Diode				Microwave mixers and low power oscillators	None

NAME OF DEVICE	CIRCUIT SYMBOL	COMMONLY USED JUNCTION SCHEMATIC	ELECTRICAL CHARACTERISTICS	MAJOR APPLICATIONS	ROUGHLY ANALOGOUS TO
Thyrector				Transient voltage suppression and arc suppression	Thyrite Two avalanche diodes in inverse-series connection
n-p-n Transistor				Amplification Switching Oscillation	Pentode Tube
p-n-p Transistor				Amplification Switching Oscillation	None
Photo Transistor				Tape readers Card readers Position sensor Tachometers	None
Unijunction Transistor (UJT)				Interval timing Oscillation Level Detector SCR Trigger	None

NAME OF DEVICE	CIRCUIT SYMBOL	COMMONLY USED JUNCTION SCHEMATIC	ELECTRICAL CHARACTERISTICS	MAJOR APPLICATIONS	ROUGHLY ANALOGOUS TO
Complementary Unijunction Transistor (CUJT)				High stability timers Oscillators and level detectors	None
Programmable Unijunction Transistor (PUT)				Programmed by two resistors for V_{DP} , I_{DP} , V_V . Function equivalent to normal UJT.	Low cost timers and oscillators Long period timers SCR trigger Level detector
Silicon Controlled Rectifier (SCR)				With anode voltage (+), SCR can be triggered by I_G remaining in conduction until anode I is reduced to zero	Power switching Phase control Inverters Choppers
Complementary Silicon Controlled Rectifier (CSCR)				Polarity complement to SCR	Ring counters Low speed logic Lamp driver
Light Activated SCR* (LASCR)				Operates similar to SCR, except can also be triggered into conduction by light falling on junctions	Relay Replacement Position controls Photoelectric applications Slave flashes

NAME OF DEVICE	CIRCUIT SYMBOL	COMMONLY USED JUNCTION SCHEMATIC	ELECTRICAL CHARACTERISTICS	MAJOR APPLICATIONS	ROUGHLY ANALOGOUS TO
Silicon Controlled Switch* (SCS)				Logic applications Counters Mixie drivers Lamp drivers	Complementary transistor pair
Silicon Unilateral Switch (SUS)				Switching Circuits Counters SCR Trigger Oscillator	Shockley or 4-layer diode
Silicon Bilateral Switch (SBS)				Switching Circuits Counters TRIAC Phase Control	Two inverse Shockley diodes
Triac				AC switching Phase control Relay replacement	Two SCR's in inverse parallel
Diac Trigger				Triac and SCR trigger Oscillator	Neon lamp

LETTER SYMBOLS AND ABBREVIATIONS FOR SEMICONDUCTOR DEVICES

Table 1: General Semiconductor Symbols

I, i	region of a device which is intrinsic and in which neither holes nor electrons predominate
N, n	region of a device where electrons are the majority carriers
NF	noise figure
P, p	region of a device where holes are the majority carriers
K_θ	thermal derating factor
T	temperature
T_A	ambient temperature
T_C	case temperature
T_J	junction temperature
T_{STG}	storage temperature
θ , or R_θ	thermal resistance
θ_{J-A}	thermal resistance, junction to ambient
θ_{J-C}	thermal resistance, junction to case
$\theta_{(t)}$	transient thermal impedance
$\theta_{J-A(t)}$	transient thermal impedance, junction to ambient
$\theta_{J-C(t)}$	transient thermal impedance, junction to case
t_d	delay time
t_f	fall time
t_{fr}	forward recovery time (diodes)
t_p	pulse time
t_r	rise time
t_{rr}	reverse recovery time (diodes)
t_s	storage time

Table 2: Signal Diode and Rectifier Diode Symbols

$V_{(BR)}$ or $V_{(BR)R}$	reverse breakdown voltage, dc
$V_{(BR)}$ or $V_{(BR)R}$	reverse breakdown voltage, instantaneous total value
I_F	forward current, dc
$I_{F(AV)}$	forward current, average value
I_F	forward current, instantaneous total value
I_i	forward current, rms value of alternating component
$I_{F(RMS)}$	forward current, rms total value
I_{FM}	forward current, maximum (peak) total value
$I_{FM(rep)}$	forward current, repetitive, maximum (peak), total value
$I_{FM(surge)}$	forward current, maximum (peak), total value of surge
I_O	output current, average rectified
I_R	reverse current, dc
I_R	reverse current, instantaneous total value
$I_{R(AV)}$	reverse current, average value
I_{RM}	reverse current, maximum (peak) total value
I_r	reverse current, rms value of alternating component
$I_{R(RMS)}$	reverse current, rms total value
L_c	conversion loss (microwave diodes)
P_F	forward power dissipation, dc
$P_{F(AV)}$	forward power dissipation, average value
P_{FM}	forward power dissipation, maximum (peak) total value
P_F	forward power dissipation, instantaneous total value

P_R	reverse power dissipation, dc
$P_{R(AV)}$	reverse power dissipation, average value
P_{RM}	reverse power dissipation, maximum (peak) total value
P_R	reverse power dissipation, instantaneous total value
V_F	forward voltage drop, dc
V_F	forward voltage drop, instantaneous total value
$V_{F(AV)}$	forward voltage drop, average value
V_{FM}	forward voltage drop, maximum (peak) total value
$V_{F(RMS)}$	forward voltage drop, total rms value
V_f	forward voltage drop, rms value of alternating component
V_R	reverse voltage, dc
V_R	reverse voltage, instantaneous total value
$V_{R(AV)}$	reverse voltage, average value
V_{RM}	reverse voltage, maximum (peak) total value
$V_{RM(wkg)}$	working peak reverse voltage, maximum (peak) total value
$V_{RM(rep)}$	repetitive peak reverse voltage, maximum (peak) total value
$V_{RM(nonrep)}$	nonrepetitive peak reverse voltage, maximum (peak) total value
$V_{R(RMS)}$	reverse voltage, total rms value
V_r	reverse voltage, rms value of alternating component

Table 3: Transistor Symbols

BV_{CBO}	obsolete—see $V_{(BR)CBO}$
BV_{CEO}	obsolete—see $V_{(BR)CEO}$
BV_{CER}	obsolete—see $V_{(BR)CER}$
BV_{CES}	obsolete—see $V_{(BR)CES}$
BV_{CEX}	obsolete—see $V_{(BR)CEX}$
BV_{EBO}	obsolete—see $V_{(BR)EBO}$
BV_R	obsolete—see $V_{(BR)R}$
C_{ibo}	open-circuit input capacitance, common base
C_{ib}	short-circuit input capacitance, common base
C_{ieo}	open-circuit input capacitance, common emitter
C_{ies}	short-circuit input capacitance, common emitter
C_{obo}	open-circuit output capacitance, common base
C_{obs}	short-circuit output capacitance, common base
C_{oeo}	open-circuit output capacitance, common emitter
C_{oes}	short-circuit output capacitance, common emitter
f_{htb}	small-signal short-circuit forward current transfer ratio cutoff frequency (common base)
f_{htc}	small-signal short-circuit forward current transfer ratio cutoff frequency (common collector)
f_{hte}	small-signal short-circuit forward current transfer ratio cutoff frequency (common emitter)
f_{max}	maximum frequency of oscillation
f_T	frequency at which small-signal forward current transfer ratio (common emitter) extrapolates to unity
g_{ME}	static transconductance (common emitter)
g_{me}	small-signal transconductance (common emitter)
G_{PB}	large-signal average power gain (common base)
G_{pb}	small-signal average power gain (common base)
G_{PC}	large-signal average power gain (common collector)
G_{pc}	small-signal average power gain (common collector)
G_{PE}	large-signal average power gain (common emitter)
G_{pe}	small-signal average power gain (common emitter)

h_{FB}	static forward current transfer ratio (common base)
h_{fb}	small-signal short-circuit forward current transfer ratio (common base)
h_{FC}	static forward current transfer ratio (common collector)
h_{fc}	small-signal short-circuit forward current transfer ratio (common collector)
h_{FE}	static forward current transfer ratio (common emitter)
h_{fe}	small-signal short-circuit forward current transfer ratio (common emitter)
h_{IB}	static input resistance (common base)
h_{ib}	small-signal short-circuit input impedance (common base)
h_{IC}	static input resistance (common collector)
h_{ic}	small-signal short-circuit input impedance (common collector)
h_{IE}	static input resistance (common emitter)
h_{ie}	small-signal short-circuit input impedance (common emitter)
h_{ob}	small-signal open-circuit output admittance (common base)
h_{oc}	small-signal open-circuit output admittance (common collector)
h_{oe}	small-signal open-circuit output admittance (common emitter)
h_{rb}	small-signal open-circuit reverse voltage transfer ratio (common base)
h_{rc}	small-signal open-circuit reverse voltage transfer ratio (common collector)
h_{re}	small-signal open-circuit reverse voltage transfer ratio (common emitter)
I_B	base current, dc
I_b	base current, rms value of alternating component
I_B	base current, instantaneous total value
I_C	collector current, dc
I_c	collector current, rms value of alternating component
I_C	collector current, instantaneous total value
I_{CBO}	collector cutoff current, dc, emitter open
I_{CEO}	collector cutoff current, dc, base open
I_{CER}	collector cutoff current, dc, with specified resistance between base and emitter
I_{CEV}	collector cutoff current, dc, with specified voltage between base and emitter
I_{CEX}	collector current, dc, with specified circuit between base and emitter
I_{CES}	collector cutoff current, dc, with base short circuited to emitter
I_{OSS}	drain current, dc, with gate shorted to emitter
I_E	emitter current, dc
I_e	emitter current, rms value of alternating component
I_{EBO}	emitter cutoff current (dc), collector open
P_{BE}	power input (dc) to the base (common emitter)
p_{BE}	power input (instantaneous total) to the base (common emitter)
P_{CB}	power input (dc) to the collector (common base)
p_{CB}	power input (instantaneous total) to the collector (common base)
P_{CE}	power input (dc) to the collector (common emitter)
p_{CE}	power input (instantaneous total) to the collector (common emitter)
P_{EB}	power input (dc) to the emitter (common base)
p_{EB}	power input (instantaneous total) to the emitter (common base)
P_{IB}	large-signal input power (common base)
p_{ib}	small-signal input power (common base)
P_{IC}	large-signal input power (common collector)
p_{ic}	small-signal input power (common collector)
P_{IE}	large-signal input power (common emitter)
p_{ie}	small-signal input power (common emitter)
P_{OB}	large-signal output power (common base)
p_{ob}	small-signal output power (common base)
P_{OC}	large-signal output power (common collector)
p_{oc}	small-signal output power (common collector)
P_{OE}	large-signal output power (common emitter)

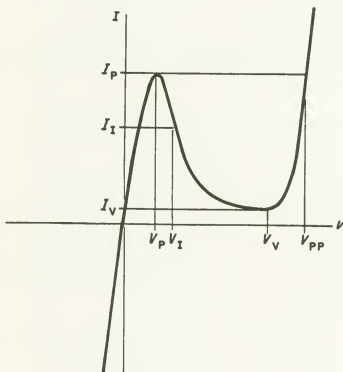
P_{oe}	small-signal output power (common emitter)
P_T	total nonreactive power input (dc) to all terminals
p_T	nonreactive power input (instantaneous total) to all terminals
R_B	external base resistance
R_C	external collector resistance
$r_{CE(sat)}$	collector-to-emitter saturation resistance
R_E	external emitter resistance
$Re(h_{ie})$	real part of the small-signal short-circuit input impedance (common emitter)
$V_{(BR)CBO}$	breakdown voltage, collector-to-base, emitter open
$V_{(BR)ICEO}$	breakdown voltage, collector-to-emitter, base open
$V_{(BR)ICER}$	breakdown voltage, collector-to-emitter, with specified resistance between base and emitter
$V_{(BR)ICES}$	breakdown voltage, collector-to-emitter, with base short-circuited to emitter
$V_{(BR)ICEX}$	breakdown voltage, collector-to-emitter, with specified circuit between base and emitter
$V_{(BR)IDGO}$	breakdown voltage, drain-to-gate, source open
$V_{(BR)IEBO}$	breakdown voltage, emitter-to-base, collector open
$V_{(BR)R}$	breakdown voltage, reverse
V_{BB}	base supply voltage
V_{BC}	base-to-collector voltage, dc
V_{bc}	base-to-collector voltage, rms value of alternating component
v_{bc}	base-to-collector voltage, instantaneous value of ac component
V_{BE}	base-to-emitter voltage, dc
V_{be}	base-to-emitter voltage, rms value of alternating component
v_{be}	base-to-emitter voltage, instantaneous value of ac component
V_{CB}	collector-to-base voltage, dc
V_{cb}	collector-to-base voltage, rms value of alternating component
v_{cb}	collector-to-base voltage, instantaneous value of ac component
$V_{CB(If)}$	dc open-circuit voltage (floating potential) between the collector and base, with the emitter biased with respect to the base
V_{CC}	collector supply voltage, dc
V_{CE}	collector-to-emitter voltage, dc
V_{ce}	collector-to-emitter voltage, rms value of alternating component
v_{ce}	collector-to-emitter voltage, instantaneous value of ac component
$V_{CE(If)}$	dc open-circuit voltage (floating potential) between the collector and emitter, with the base biased with respect to the emitter
V_{CEO}	collector-to-emitter voltage, dc, with base open
$V_{CEO(sus)}$	collector-to-emitter (breakdown) sustaining voltage with base open
V_{CER}	collector-to-emitter voltage, dc with specified resistor between base and emitter
$V_{CER(sus)}$	collector-to-emitter (breakdown) sustaining voltage with specified resistor between base and emitter
V_{CES}	collector-to-emitter voltage, dc with base short circuited to emitter
$V_{CES(sus)}$	collector-to-emitter (breakdown) sustaining voltage with base short-circuited to emitter
V_{CEX}	collector-to-emitter voltage, dc with specified circuit between base and emitter
$V_{CEX(sus)}$	collector-to-emitter (breakdown) sustaining voltage with specified circuit between base and emitter
$V_{CE(sat)}$	collector-to-emitter saturation voltage, dc
V_{EB}	emitter-to-base voltage, dc
$V_{EB(If)}$	dc open-circuit voltage (floating potential) between the emitter and base, with the collector biased with respect to the base
V_{eb}	emitter-to-base voltage, rms value of alternating component
v_{eb}	emitter-to-base voltage, instantaneous value of ac component
V_{EC}	emitter-to-collector voltage, dc

$V_{EC(10)}$	dc open-circuit voltage (floating potential) between the emitter and collector, with the base biased with respect to the collector
V_{ec}	emitter-to-collector voltage, rms value of alternating component
V_{ec}	emitter-to-collector voltage, instantaneous value of ac component
V_{EE}	emitter supply voltage
V_{RT}	reach-through voltage

Table 4: Tunnel Diode Symbols

I_I	inflection point current
I_P	peak point current
I_V	valley point current
r_i	dynamic resistance at inflection point
V_{PP}	projected peak point voltage [forward voltage point (greater than the peak voltage), at which the current is equal to the peak current]
V_I	inflection point voltage
V_P	peak point voltage
V_V	valley point voltage

Typical Characteristics



COMPARATIVE CHARACTERISTICS OF ACTIVE DEVICES

Characteristic	Vacuum Tube	Small-Signal Transistor	High-Power Transistor	Junction Fet	Mosfet
Input impedance	High	^a	Very low	High	Very high
Output impedance	High	^a	Low/moderate	High	High
Noise	Low	Low	Moderate	Low	Unpredictable
Warm-up time	Long	Short	Short	Short	Short
Power consumption	Large	Small	Moderate	Very Small	Very small
Aging	Appreciable	Low	Low	Low	Moderate
Reliability	Poor	Excellent	Very good	Excellent	Very good
Overload sensitivity	Excellent	Good	Fair	Good	Poor
Size	Large	Small	Moderate	Small	Small

^aImpedances depend on circuit arrangement:

	Input Impedance	Output Impedance
For common base	Low (10's of ohms)	High (megohms)
For common emitter	Medium (kilohms)	Medium (10's of kilohms)
For common collector	High (100's of kilohms)	Low (100's of ohms)

SUMMARY OF INTEGRATED CIRCUIT PROPERTIES

This table compares pertinent characteristics of present day and future ICs.

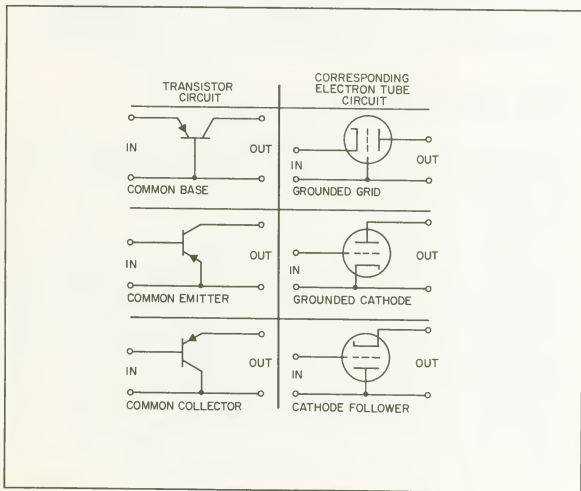
Properties	Current technologies								Future (1985-1990)	
	TTL	LSTTL	ECL	PL	PMOS	NMOS	BULK CMOS	CMOS/SOS	SOS	GaAs
Relative process maturity (1-10)	10 (8)*	9 (4 to 5)*	8 to 9 (3 to 5)	4	10	9	8	4	2	1
Process complexity (No. processing steps)	18 to 22†	18 to 23†	19 to 23†	13 to 17	8 to 14	9 to 15	14 to 17	14 to 20	14 to 20	18
Logic complexity (No. components, 2-input gates)	12	12	8	3 to 4	3	3	4	4	3 to 4	2
Packing Density (gates/mm ²)	10 to 20	20 to 40	15 to 20	75 to 150	75 to 150	100 to 200	40 to 90	100 to 500	200 to 500	300 to 1000
Propagation delay, ns (typical value)	8 to 30 (10)	2 to 10 (5)	0.7 to 2 (2)	7 to 50 (20)	30 to 200 (100)	4 to 25 (15)	10 to 35 (20)	4 to 20 (10)	0.2 to 0.4 (0.3)	0.05 to 0.1 (0.07)
Speed-power product (pJ)	30 to 150	10 to 60	15 to 60	0.2 to 2.0	50 to 500	5 to 50	2 to 40	0.5 to 30	0.1 to 0.2	0.01 to 0.1
Typical supply voltages (volts)	+5.0	+5.0	-5.2	+0.8 to +1.0	-15 to +20	+5.0	+10.0	+10.0	+2.0	+1.2
Signal swing (volts)	0.2 to 3.4	0.2 to 3.4	-0.8 to -1.7	0.2 to 0.8	0.0 to -15.0	0.2 to 3.4	0.0 to 10.0	0.0 to 10.0	0.0 to 2.0	0.0 to 0.8
Guaranteed noise margin (volts)	0.3 to 0.4	0.3 to 0.4	0.125	<0.1	1 to 2	0.5 to 20	3.5 to 4.5	3.5 to 4.5	0.2 to 0.8	0.2 to 0.3
Neutron hardness capability (n/cm ²)	0.2 to 10 ⁶	0.2 to 10 ¹⁶	0.5 to 2x10 ¹⁶	1 to 5 x 10 ¹³	>10 ¹⁶ to 10 ¹⁸	>10 ¹⁶ to 10 ¹⁸	>10 ¹⁶ to 10 ¹⁸	>10 ¹⁶ to 10 ¹⁸	>10 ¹⁶ to 10 ¹⁸	>10 ¹⁶
Total dose (r) hardness capability (rads)	10 ⁶ to 10 ⁸	10 ⁶ to 10 ⁸	10 ⁶ to 10 ⁸	10 ⁶ to 10 ⁸	10 ⁶	1 to 5 x 10 ⁶	10 ⁶ to 10 ⁸	10 ⁶ to 10 ⁸	10 ⁶ to 10 ⁸	>10 ⁸
Dose rate (r/s) or photo-current hardness capability (rad/s)	0.5 to 2x10 ¹⁶	0.2 to 10 ¹⁶	0.2 to 10 ¹⁶	0.1 to 4 x 10 ¹⁶	0.1 to 5 x 10 ⁶	0.1 to 5 x 10 ⁶	0.5 to 2 x 10 ⁶	0.2 to 10 ¹¹	0.5 to 10 ¹¹	>10 ¹⁶

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ANALOGY BETWEEN THE THREE BASIC JUNCTION TRANSISTOR CIRCUITS AND THEIR EQUIVALENT ELECTRON TUBE CIRCUITS

A transistor can be operated with the input signal applied to the base and the output taken from the collector (common emitter), with the input signal applied to the emitter and the output taken from the collector (common base), or with the input signal applied to the base and the output taken from the emitter (common collector or emitter follower). The performance characteristics of these three connections correspond roughly to the three tube connections shown below, with the exception that the input impedance is generally lower in the transistor circuit. General characteristics of these three connections are given in the table.

Common Emitter	Common Base	Common Collector
Large current gain	Approximate unity current gain	Large current gain
Large voltage gain	Large voltage gain	Approximate unity voltage gain
Highest power gain	Intermediate power gain	Lowest power gain
Low input resistance	Very low input resistance	High input resistance
High output resistance	Very high output resistance	Low output resistance
Analogous to grounded cathode	Analogous to grounded grid	Analogous to cathode follower generally



DEFINITIONS OF EQUIVALENT CIRCUIT PARAMETERS

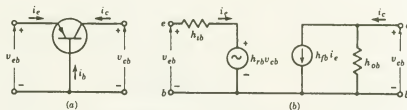
Parameter	Common Base	Common Emitter	Common Collector	Definition
z	$z_{11}, z_{11b}, \text{ or } z_{ib}$	$z_{11e} \text{ or } z_{ie}$	$z_{11c} \text{ or } z_{ic}$	Input impedance with open-circuit output
	$z_{12}, z_{12b}, \text{ or } z_{rb}$	$z_{12e} \text{ or } z_{re}$	$z_{12c} \text{ or } z_{rc}$	Reverse transfer impedance with open-circuit input
	$z_{21}, z_{21b}, \text{ or } z_{fb}$	$z_{21e} \text{ or } z_{fe}$	$z_{21c} \text{ or } z_{fc}$	Forward transfer impedance with open-circuit output
y	$z_{22}, z_{22b}, \text{ or } z_{ob}$	$z_{22e} \text{ or } z_{oe}$	$z_{22c} \text{ or } z_{oc}$	Output impedance with open-circuit input
	$y_{11}, y_{11b}, \text{ or } y_{ib}$	$y_{11e} \text{ or } y_{ie}$	$y_{11c} \text{ or } y_{ic}$	Input admittance with short-circuit output
	$y_{12}, y_{12b}, \text{ or } y_{rb}$	$y_{12e} \text{ or } y_{re}$	$y_{12c} \text{ or } y_{rc}$	Reverse transfer admittance with short-circuit input
h	$y_{21}, y_{21b}, \text{ or } y_{fb}$	$y_{21e} \text{ or } y_{fe}$	$y_{21c} \text{ or } y_{fc}$	Forward transfer admittance with short-circuit output
	$y_{22}, y_{22b}, \text{ or } y_{ob}$	$y_{22e} \text{ or } y_{oe}$	$y_{22c} \text{ or } y_{oc}$	Output admittance with short-circuit input
	$h_{11}, h_{11b}, \text{ or } h_{ib}$	$h_{11e} \text{ or } h_{ie}$	$h_{11c} \text{ or } h_{ic}$	Input impedance with short-circuit output
	$h_{12}, h_{12b}, \text{ or } h_{rb}$	$h_{12e} \text{ or } h_{re}$	$h_{12c} \text{ or } h_{rc}$	Reverse open-circuit voltage amplification factor
	$h_{21}, h_{21b}, \text{ or } h_{fb}$	$h_{21e} \text{ or } h_{fe}$	$h_{21c} \text{ or } h_{fc}$	Forward short-circuit current amplification factor
	$h_{22}, h_{22b}, \text{ or } h_{ob}$	$h_{22e} \text{ or } h_{oe}$	$h_{22c} \text{ or } h_{oc}$	Output admittance with open-circuit input
Note: $h_{11} = 1/y_{11}$ and $h_{22} = 1/z_{22}$.				

Typical Transistor Parameters

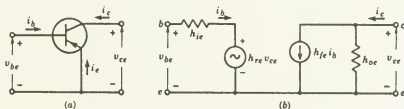
Common Base	Common Emitter	Common Collector
$h_{11} = 39 \text{ ohms}$	$h_{11} = 2,000 \text{ ohms}$	$h_{11} = 2,000 \text{ ohms}$
$h_{12} = 380 \times 10^{-6}$	$h_{12} = -600 \times 10^{-6}$	$h_{12} = 1$
$h_{21} = -0.98$	$h_{21} = 50$	$h_{21} = -51$
$h_{22} = 0.49 \mu\text{mho}$	$h_{22} = 25 \mu\text{mhos}$	$h_{22} = 25 \mu\text{mhos}$

EQUIVALENT CIRCUITS FOR SMALL-SIGNAL LOW-FREQUENCY TRANSISTOR STAGES

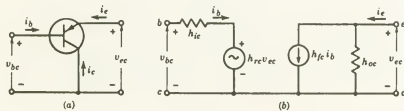
Small-signal, low-frequency, T-equivalent circuits for transistor stages



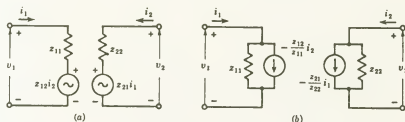
Common-base configuration (a) and hybrid equivalent circuit (b).



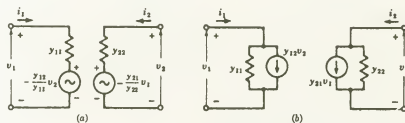
Common-emitter configuration (a) and hybrid equivalent circuit (b).



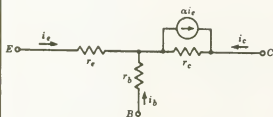
Common-collector configuration (a) and hybrid equivalent circuit (b).



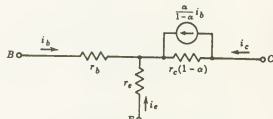
z-Parameter equivalent circuit.



y-Parameter equivalent circuit.



T-equivalent circuit, common base.



T-equivalent circuit, common emitter.

TRANSISTOR PARAMETER CONVERSION TABLES

- (A) Common-base h parameters in terms of common-emitter, common-collector, and T parameters.
 (B) Common-collector h parameters in terms of common-emitter, common-base, and T parameters.
 (C) Common-emitter h parameters in terms of common-base, common-collector, and T parameters.
 (D) T parameters in terms of common-emitter, common-base, and common-collector parameters.

h parameter	Common emitter	Common collector	T equivalent circuit
h_{ib}	$\frac{h_{ie}}{(1+h_{ie})(1-h_{re})+h_{ie}h_{oe}} \approx \frac{h_{ie}}{1+h_{ie}}$	$\frac{h_{ic}}{h_{ic}h_{oc}-h_{ic}h_{ic}} \approx \frac{h_{ic}}{h_{ic}}$	$r_e + (1-\alpha)r_b$
h_{ob}	$\frac{h_{ie}h_{oe}-h_{re}(1+h_{ie})}{(1+h_{ie})(1-h_{re})+h_{ie}h_{oe}} \approx \frac{h_{ie}h_{oe}-h_{re}}{1+h_{ie}}$	$\frac{h_{ic}(1-h_{ic})+h_{ic}h_{oc}}{h_{ic}h_{oc}-h_{ic}h_{ic}} \approx h_{ic}-1$	$\frac{r_b}{r_c+r_b} \approx \frac{r_b}{r_c}$
h_{rb}	$\frac{h_{re}(1-h_{re})-h_{ie}h_{oe}}{(1+h_{ie})(1-h_{re})+h_{ie}h_{oe}} \approx \frac{h_{re}}{1+h_{ie}}$	$\frac{h_{ic}(1+h_{ic})-h_{ic}h_{oc}}{h_{ic}h_{oc}-h_{ic}h_{ic}} \approx \frac{1+h_{ic}}{h_{ic}}$	$-\alpha$
h_{bb}	$\frac{h_{oe}}{(1+h_{ie})(1-h_{re})+h_{ie}h_{oe}} \approx \frac{h_{oe}}{1+h_{ie}}$	$\frac{h_{oc}}{h_{ic}h_{oc}-h_{ic}h_{ic}} \approx \frac{h_{oc}}{h_{ic}}$	$\frac{1}{r_c+r_b} \approx \frac{1}{r_c}$
h parameter	Common emitter	Common base	T equivalent circuit
h_{ic}	h_{ie}	$\frac{h_{ib}}{(1+h_{ib})(1-h_{rb})+h_{ib}h_{ob}} \approx \frac{h_{ib}}{1+h_{ib}}$	$r_b + \frac{r_e' r_c}{r_e+r_e'-\alpha r_c} \approx r_b + \frac{r_e}{1-\alpha}$
h_{rc}	$1-h_{re}$	$\frac{1+h_{rb}}{(1+h_{rb})(1-h_{rb})+h_{ob}h_{ib}} \approx 1$	$\frac{r_e'-\alpha r_c}{r_e+r_e'-\alpha r_c} \approx 1 - \frac{r_e}{(1-\alpha)r_c}$
h_{ic}	$(1+h_{ie})$	$\frac{h_{ib}-1}{(1+h_{ib})(1-h_{rb})+h_{ob}h_{ib}} \approx \frac{1}{1+h_{ib}}$	$\frac{r_e}{r_e+r_e'-\alpha r_c} \approx \frac{-1}{1-\alpha}$
h_{oc}	h_{oe}	$\frac{h_{ob}}{(1+h_{rb})(1-h_{rb})+h_{ob}h_{ib}} \approx \frac{h_{ob}}{1+h_{rb}}$	$\frac{1}{r_e+r_e'-\alpha r_c} \approx \frac{1}{(1-\alpha)r_c}$
h parameter	Common base	Common collector	T equivalent circuit
h_{ie}	$\frac{h_{ib}}{(1+h_{ib})(1-h_{rb})+h_{ob}h_{ib}} \approx \frac{h_{ib}}{1+h_{ib}}$	h_{ic}	$r_b + \frac{r_e' r_c}{r_e+r_e'-\alpha r_c} \approx r_b + \frac{r_e}{1-\alpha}$
h_{re}	$\frac{h_{ib}h_{ob}-h_{rb}(1+h_{ib})}{(1+h_{ib})(1-h_{rb})+h_{ob}h_{ib}} \approx \frac{h_{ib}h_{ob}-h_{rb}}{1+h_{ib}}$	$1-h_{ic}$	$\frac{r_e}{r_e+r_e'-\alpha r_c} \approx \frac{r_e}{(1-\alpha)r_c}$
h_{ic}	$\frac{h_{ib}(1-h_{rb})-h_{ob}h_{ib}}{(1+h_{ib})(1-h_{rb})+h_{ob}h_{ib}} \approx \frac{-h_{rb}}{1+h_{ib}}$	$-(1+h_{ic})$	$\frac{\alpha r_c - r_e}{r_e+r_e'-\alpha r_c} \approx \frac{\alpha}{1-\alpha}$
h_{oe}	$\frac{h_{ob}}{(1+h_{ib})(1-h_{rb})+h_{ob}h_{ib}} \approx \frac{h_{ob}}{1+h_{ib}}$	h_{oc}	$\frac{1}{r_e+r_e'-\alpha r_c} \approx \frac{1}{(1-\alpha)r_c}$
T parameter	Common emitter	Common base	Common collector
α	$\frac{h_{ie}(1-h_{re})+h_{ie}h_{oe}}{(1+h_{ie})(1-h_{re})+h_{ie}h_{oe}} \approx \frac{h_{ie}}{1+h_{ie}}$	h_{rb}	$\frac{h_{ic}h_{oc}-h_{ic}(1+h_{ic})}{h_{ic}h_{oc}-h_{ic}h_{ic}} \approx \frac{1+h_{ic}}{h_{ic}}$
r_c	$\frac{h_{ie}+1}{h_{oe}}$	$\frac{1}{h_{ob}}$	$\frac{h_{ic}}{h_{oc}}$
r_e	$\frac{h_{re}}{h_{oe}}$	$h_{ib} + (1+h_{ib})\frac{h_{ib}}{h_{ob}}$	$\frac{1}{h_{oe}}$
r_b	$\frac{h_{re}(1+h_{ie})}{h_{oe}}$	$\frac{h_{ib}}{h_{ob}}$	$h_{ic} + \frac{h_{ic}(1-h_{ic})}{h_{oc}}$
α	$\frac{h_{ie}+h_{re}}{1+h_{ie}}$	$\frac{1}{h_{ob}}$	$\frac{h_{ic}+h_{ic}}{h_{ic}}$

- (E) Input impedance and output impedance in terms of h and T parameters.
 (F) Insertion power gain and transducer power gain in terms of h parameters.
 (G) Current gain and voltage gain in terms of h and T parameters.
 (H) Available power gain and operating power gain in terms of h parameters.

	Input impedance	Output impedance
h parameter	$Z_i = \frac{v_i}{i_i} = h_i - \frac{h_f h_r Z_L}{1 + h_o Z_L}$	$Z_o = \frac{v_o}{i_o} = \frac{1}{h_o - \frac{h_f h_r}{h_i + Z_g}}$
(E) Common base T-equivalent circuit	$r_e + r_b \left(\frac{r_c - a r_e + R_L}{r_c + r_b + R_L} \right) \cong r_e + r_b (1 - \alpha)$	$r_c + r_b \left(1 - \frac{a r_e + r_b}{r_e + r_b + R_g} \right) \cong r_c$
(E) Common emitter T-equivalent circuit	$r_b + \frac{r_e (r_c + R_L)}{r_c - a r_e + r_e + R_L} \cong r_b + \frac{r_e}{1 - \alpha}$	$r_c - a r_e + r_e \left(1 + \frac{a r_e - r_e}{r_e + r_b + R_g} \right) \cong \frac{r_c}{1 - \alpha}$
(E) Common collector T-equivalent circuit	$r_b + \frac{r_c (r_e + R_L)}{r_c - a r_e + r_e + R_L} \cong r_b + \frac{r_e + R_L}{1 - \alpha}$	$r_e + (r_b + R_g) \frac{r_c - a r_e}{r_c + r_b + R_g}$
(F)	Insertion power gain power into load $\left(\frac{\text{power generator would deliver directly}}{\text{maximum available generator power}} \right)$	Transducer power gain power into load $\left(\frac{\text{maximum available generator power}}{\text{power into load}} \right)$
h parameter where Z_g and Z_L are pure resistance	$G_i = \frac{h_f^2 (R_g + R_L)^2}{[(h_i + R_g)(1 + h_o R_L) - h_f h_r R_L]^2}$	$G_t = \frac{4 h_f^2 R_g R_L}{[(h_i + R_g)(1 + h_o R_L) - h_f h_r R_L]^2}$
	Current gain	Voltage gain
h parameter	$A_i = \frac{i_o}{i_i} = \frac{h_f}{1 + h_o Z_L}$	$A_v = \frac{v_o}{v_i} = \frac{1}{h_r - \frac{h_i}{Z_L} \left(\frac{1 + h_o Z_L}{h_f} \right)}$
(G) Common base T-equivalent circuit	$\frac{a r_e + r_b}{r_c + r_b + R_L} \cong \alpha$	$\frac{(a r_e + r_b) R_L}{r_e (r_c + r_b + R_L) + r_b (r_c - a r_e + R_L)} \cong \frac{\alpha R_L}{r_e + r_b (1 - \alpha)}$
(G) Common emitter T-equivalent circuit	$\frac{-(a r_e - r_e)}{r_c - a r_e + r_e + R_L} \cong \frac{\alpha}{1 - \alpha}$	$\frac{-(a r_e - r_e) R_L}{r_e (r_e + R_L) + r_b (r_c - a r_e + r_e + R_L)} \cong -\frac{\alpha R_L}{r_e + r_b (1 - \alpha)}$
(G) Common collector T-equivalent circuit	$\frac{r_c}{r_c - a r_e + r_e + R_L} \cong \frac{1}{1 - \alpha}$	$\frac{r_e R_L}{r_c (r_e + R_L) + r_b (r_c - a r_e + r_e + R_L)} \cong \frac{1}{1 + r_e + r_b \frac{1 - \alpha}{R_L}}$
(H)	Available power gain maximum available output power maximum available generator power	Operating power gain power into load power into transistor
h parameter where Z_g and Z_L are pure resistance	$G_a = \frac{h_f^2 R_g}{(h_i + R_g)[h_o(h_i + R_g) - h_f h_r]}$	$G_1 = A_v A_i = \frac{v_o i_o}{v_i i_i} = \left(\frac{h_f}{1 + h_o R_L} \right) h_r \frac{h_i}{R_L} \left(\frac{1 + h_o R_L}{h_f} \right)$

- (I) Z parameters in terms of h parameters.
 (J) Y parameters in terms of h parameters.
 (K) Common emitter z parameters in terms of common collector and common base z parameters and T parameters.
 (L) Common emitter y parameters in terms of common collector and common base y parameters and T parameters.

	Common emitter	Common base	Common collector
(I)	$z_{11b} = \frac{\Delta h}{h_{oe}}$	$\frac{\Delta h}{h_{ob}}$	$\frac{1}{h_{oc}}$
	$z_{12b} = \frac{\Delta h - h_{re}}{h_{oe}}$	$\frac{h_{rb}}{h_{ob}}$	$\frac{1 + h_{fe}}{h_{oc}}$
	$z_{21b} = \frac{\Delta h + h_{fe}}{h_{oe}}$	$\frac{-h_{rb}}{h_{ob}}$	$\frac{1 - h_{re}}{h_{oc}}$
	$z_{22b} = \frac{d}{h_{oe}}$	$\frac{1}{h_{ob}}$	$\frac{d}{h_{oc}}$
(J)	$y_{11b} = \frac{d}{h_{ie}}$	$\frac{1}{h_{ob}}$	$\frac{d}{h_{ic}}$
	$y_{12b} = \frac{h_{re} + h_{fe}}{h_{ie}}$	$\frac{h_{rb}}{h_{ob}}$	$\frac{1 + h_{fe}}{h_{ic}}$
	$y_{21b} = \frac{\Delta h + h_{fe}}{h_{ie}}$	$\frac{h_{rb}}{h_{ob}}$	$\frac{h_{re} - 1}{h_{ic}}$
	$y_{22b} = \frac{\Delta h}{h_{ie}}$	$\frac{\Delta h}{h_{ob}}$	$\frac{1}{h_{ic}}$

$\Delta h = h_i h_o - h_r h_f$
 $d = (1 + h_f)(1 - h_r) + h_i h_o \cong 1 + h_f$

z parameter	Common collector	Common base	T equivalent-circuit
(K)	$z_{11e} = z_{11} - z_{12} - z_{21} + z_{22}$	z_{11}	$r_e + r_b$
	$z_{12e} = z_{22} - z_{12}$	$z_{11} - z_{12}$	r_e
	$z_{21e} = z_{22} - z_{21}$	$z_{11} - z_{21}$	$r_e - \alpha r_c$
	$z_{22e} = z_{22}$	$z_{11} - z_{12} - z_{21} + z_{22}$	$r_e + r_c(1 - \alpha)$
y parameter	Common collector	Common base	T equivalent-circuit
(L)	$y_{11e} = y_{11}$	$y_{11} + y_{12} + y_{21} + y_{22}$	$\frac{r_e + r_c(1 - \alpha)}{\Delta}$
	$y_{12e} = -(y_{11} + y_{12})$	$-(y_{12} + y_{22})$	$-\frac{r_e}{\Delta}$
	$y_{21e} = -(y_{11} + y_{21})$	$-(y_{21} + y_{22})$	$-\frac{r_e - \alpha r_c}{\Delta}$
	$y_{22e} = y_{11} + y_{12} + y_{21} + y_{22}$	y_{22}	$\frac{r_e + r_b}{\Delta}$

$\Delta = r_e r_b + r_c [r_e + r_b(1 - \alpha)]$

- (M) Common base z parameters in terms of common emitter and common collector z parameters and T parameters.
- (N) Common base y parameters in terms of common emitter and common collector y parameters and T parameters.
- (O) Common collector z parameters in terms of common emitter and common base z parameters and T parameters.
- (P) Common collector y parameters in terms of common emitter and common base y parameters and T parameters.
- (Q) Input impedance, output impedance, voltage gain, and current gain in terms of z and y parameters.

z parameter	Common emitter	Common collector	T-equivalent circuit	
z_{11b}	z_{11}	$z_{11} \quad z_{12} \quad z_{21} + z_{22}$	$r_e + r_b$	
z_{12b}	$z_{11} \quad z_{12}$	$z_{11} \quad z_{21}$	r_b	
z_{21b}	$z_{11} \quad z_{21}$	$z_{11} \quad z_{12}$	$r_b + \beta r_c$	
z_{22b}	$z_{11} \quad z_{12} \quad z_{21} + z_{22}$	z_{11}	$r_b + r_c$	
y parameter	Common emitter	Common collector	T-equivalent circuit	
y_{11b}	$y_{11} + y_{12} + y_{21} + y_{22}$	y_{22}	$\frac{r_b + r_c}{\Delta}$	
y_{12b}	$(y_{12} + y_{22})$	$(y_{21} + y_{22})$	$\frac{r_b}{\Delta}$	
y_{21b}	$(y_{21} + y_{22})$	$(y_{12} + y_{22})$	$\frac{r_b + \beta r_c}{\Delta}$	
y_{22b}	y_{22}	$y_{11} + y_{12} + y_{21} + y_{22}$	$\frac{r_c + r_b}{\Delta}$	
$\Delta = r_e r_b + r_c [r_e + r_b (1 - \beta)]$				
z parameter	Common emitter	Common base	T-equivalent circuit	
z_{11c}	$z_{11} \quad z_{12} \quad z_{21} + z_{22}$	z_{22}	$r_b + r_c$	
z_{12c}	$z_{22} \quad z_{12}$	$z_{22} \quad z_{21}$	$r_c (1 - \beta)$	
z_{21c}	$z_{22} \quad z_{21}$	$z_{22} \quad z_{12}$	r_c	
z_{22c}	z_{22}	$z_{11} - z_{12} - z_{21} + z_{22}$	$r_e + r_c (1 - \beta)$	
y parameter	Common emitter	Common base	T-equivalent circuit	
y_{11c}	y_{11}	$y_{11} + y_{12} + y_{21} + y_{22}$	$\frac{r_e + r_c (1 - \beta)}{\Delta}$	
y_{12c}	$(y_{11} + y_{12})$	$-(y_{11} + y_{21})$	$\frac{-r_c (1 - \beta)}{\Delta}$	
y_{21c}	$(y_{11} + y_{21})$	$(y_{11} + y_{12})$	$\frac{-r_c}{\Delta}$	
y_{22c}	$y_{11} + y_{12} + y_{21} + y_{22}$	y_{11}	$\frac{r_b + r_c}{\Delta}$	
$\Delta = r_e r_b + r_c [r_e + r_b (1 - \beta)]$				
Parameter	Input impedance	Output impedance	Voltage gain	Current gain
z	$\frac{\Delta z + z_{11} z_L}{z_{22} + z_L}$	$\frac{\Delta z + z_{22} z_g}{z_{11} + z_g}$	$\frac{z_{21} z_L}{\Delta z + z_{11} z_L}$	$\frac{-z_{21}}{z_{22} + z_L}$
y	$\frac{y_{22} + Y_L}{\Delta y + y_{11} Y_L}$	$\frac{y_{11} + Y_g}{\Delta y + y_{22} Y_g}$	$\frac{y_{21}}{y_{22} + Y_L}$	$\frac{y_{21} Y_L}{\Delta y + y_{11} Y_L}$
$\Delta z = z_{11} z_{22} - z_{12} z_{21} \quad \Delta y = y_{11} y_{22} - y_{12} y_{21}$				

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MULTIVIBRATOR DESIGN CURVES

The accompanying curves permit an easy and rapid determination of the frequency of oscillation of a symmetrical-astable (free-running) multivibrator, and the pulse duration (t_p) of a monostable (one-shot) multivibrator. The pulse duration of the astable multivibrator output also can be read from the curve.

The expressions on which the curves are based are derived readily. The expression for the voltage at the base of the "off" transistor is

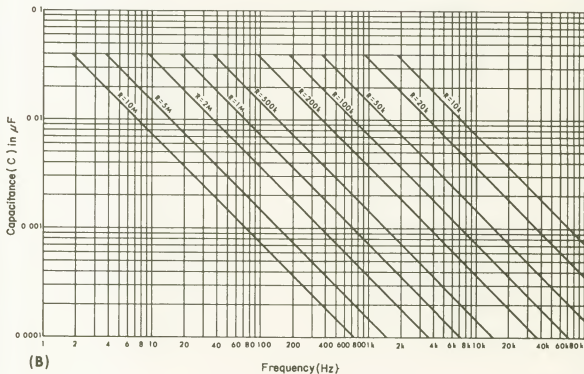
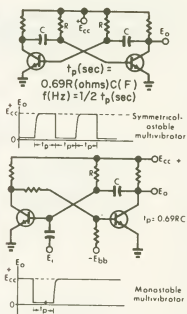
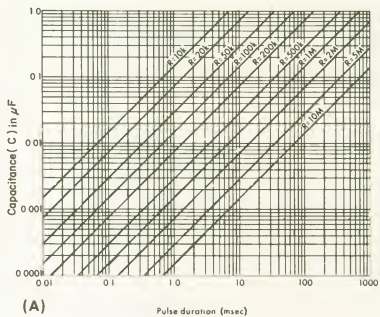
$$e_b = E_{cc} (1 - 2e^{-t/RC}) + V_{be}$$

where V_{be} is the base-to-emitter voltage of an "on" transistor. The above equation assumes that base-to-emitter breakdown is prevented by using transistors whose base-to-emitter breakdown voltage is greater than E_{cc} volts, or by connecting a diode in either the base or emitter lead.

The "off" transistor turns on when $e_b = V_{be}$, or $e^{-t/RC} = 1/2$ where t is the "off" time (t_p) at the end of which time $e_b = V_{be}$. Solving the equation yields $t_p = 0.69 RC$. The curves in graph (A) are plots of this equation. For the monostable multivibrator, t_p is the pulse duration. The period of the symmetrical-astable multivibrator is equal to $2t_p$.

Graph (B) is a family of curves of frequency of the symmetrical-astable multivibrator versus capacitance C for various values of resistance R . Since the period of the output wave is $2t_p$, the equation for frequency is given as $f = 1/1.38RC$, from which the curves were plotted.

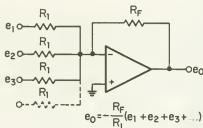
FOR EXAMPLE: Find the value of C required to generate a frequency of 500 Hz from a free-running multivibrator, or a 1 msec pulse from a monostable. In both cases the value of R is limited to 100,000 ohms by the beta of the transistor selected. The curves indicated a value of 0.0145 μF for the capacitor.



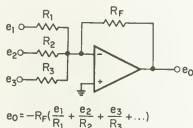
OPERATIONAL AMPLIFIERS

An operational amplifier is essentially a very high gain dc amplifier whose open-loop gain is generally high enough when compared with the closed-loop gain so that the closed-loop characteristics depend solely on the feedback element. Circuit applications for which operational amplifiers can be used are illustrated below.

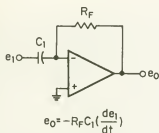
Summing



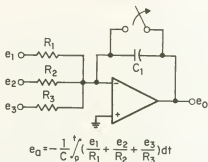
Scaling



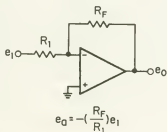
Differentiation



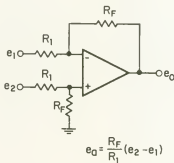
Integration

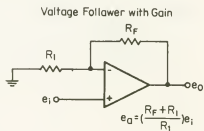
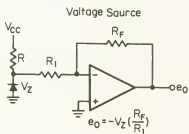
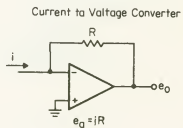
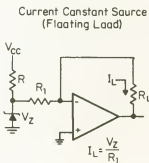
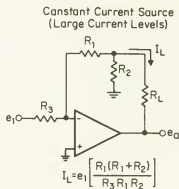
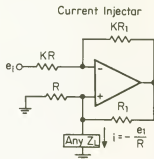


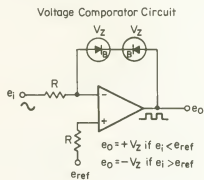
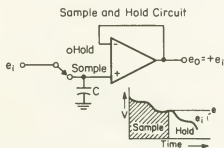
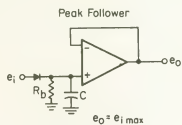
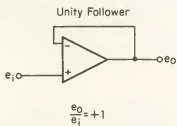
Voltage Gain
(Multiplication)



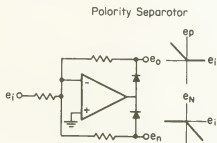
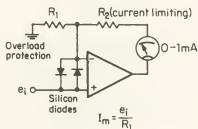
Subtraction



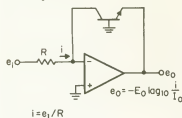




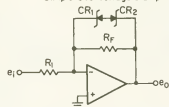
High-impedance Low-voltage Voltmeter



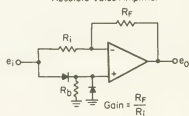
Logarithmic Transconductor



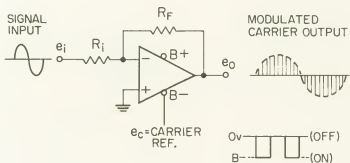
Simple Overvoltage Clamp



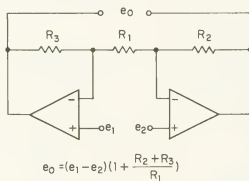
Absolute Value Amplifier



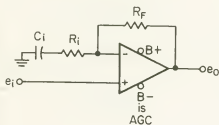
Modulator-Demodulator (Half-Wave)



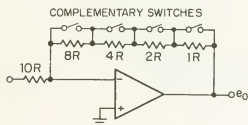
Floating Load



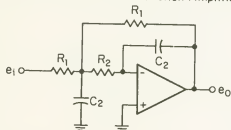
Automatic Gain Control Amplifier



D/A Converter

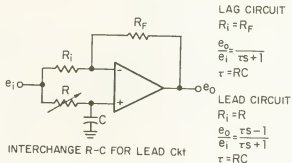


Second-Order Transfer Function Amplifier

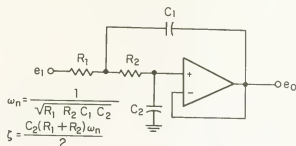


$$\frac{e_o}{e_i} = \frac{1}{(R_1 R_2 C_1 C_2) s^2 + C_1 (2R_2 + R_1) s + 1}$$

Adjustable Log (0 to -180°) Amplifier



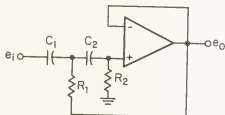
Second-order Low-pass Active Filter (Two Pole)



$$\frac{e_o}{e_i} = \frac{1}{R_1 R_2 C_1 C_2 s^2 + C_2 (R_1 + R_2) s + 1}$$

$$= \frac{1}{\left(\frac{s}{\omega_n}\right)^2 + 2\zeta \frac{s}{\omega_n} + 1}$$

Second-Order High-Pass Active Filter

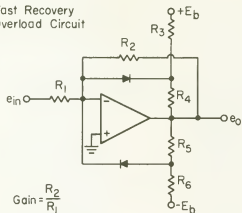


WHERE: $d = \frac{\tau_1 + R_1 C_2}{\sqrt{\tau_1 \tau_2}}$

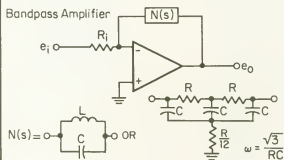
$$\frac{e_o}{e_i} = \frac{\left(\frac{s}{\omega_n}\right)^2}{\left(\frac{s}{\omega_n}\right)^2 + d \left(\frac{s}{\omega_n}\right) + 1}$$

AND: $\omega_n^2 = \frac{1}{\tau_1 \tau_2}$
 $\tau_1 = R_1 C_1$
 $\tau_2 = R_2 C_2$

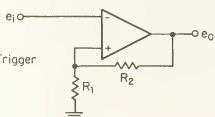
Fast Recovery
Overload Circuit



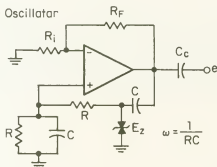
Bandpass Amplifier



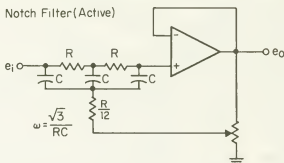
Schmitt Trigger



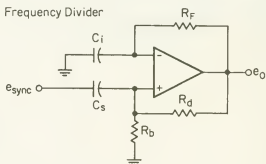
Wien Bridge Oscillator



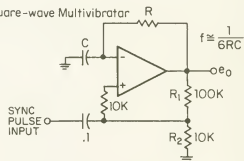
Notch Filter(Active)



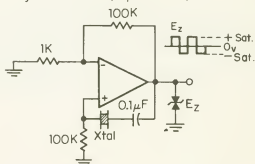
Frequency Divider



Square-wave Multivibrator



Crystal Oscillator(Square Wave)



GLOSSARY OF OPERATIONAL AMPLIFIER TERMS

Common-mode gain	Ratio of output voltage over input voltage applied to (+) and (-) terminal in parallel.
Common-mode rejection ratio (CMRR)	Ratio of an op amp's open-loop gain to its common-mode gain.
Differential-input voltage range	Range of voltages that may be applied between input terminals without forcing the op amp to operate outside its specifications.
Differential Input Impedance ($Z_{in\ diff}$)	Impedance measured between (+) and (-) input terminals.
Drift, input voltage	Change in output voltage divided by open-loop gain, as a function of temperature or time.
Input voltage offset	Dc potential required at the differential input to produce an output voltage of zero.
Input bias current	Input current required by (+) and (-) inputs for normal operation.
Input offset current	Difference between (+) and (-) input bias currents.
Offset	Measure of unbalance between halves of a symmetrical circuit.
Open-loop bandwidth	Without feedback, frequency at which amplifier gain falls 3 dB below its low-frequency value.
Open-loop voltage gain (A_{vol})	Differential gain of an op amp with no external feedback.
Slew rate	Maximum rate at which output voltage can change with time; usually given in volts per microsecond.

EUROPEAN SEMICONDUCTOR NUMBERING SYSTEM (PRO ELECTRON CODE)

First Letter	Second Letter	Third, Fourth, and Fifth Character
Material	Type	Serial Code
<p>A Germanium</p> <p>B Silicon</p> <p>C Compound materials, such as cadmium sulfide or gallium arsenide used in semiconductor devices. (Energy gap band of 1.3 or more electron-volts)</p> <p>D Materials with an energy gap band of less than 0.6 electron-volts such as indium antimonide</p> <p>R Radiation detectors, photoconductive cells. Hall effect generators, etc.</p>	<p>A Low-power diode, voltage-variable capacitor</p> <p>B Varicap</p> <p>C Small-signal audio transistor</p> <p>D Audio power transistor</p> <p>E Tunnel diode</p> <p>F Small-signal rf transistor</p> <p>G Miscellaneous</p> <p>H Field probe</p> <p>K Hall generator</p> <p>L Rf-power transistor</p> <p>M Hall modulators and multipliers</p> <p>P Photodiode, phototransistor, photoconductive cell (LDR), radiation device</p> <p>R Low-power controlled rectifier</p> <p>S Low-power switching transistor</p> <p>T Breakdown devices, high-power controlled rectifier, Shockley diode, Thyristor, pnpn diodes</p> <p>U High-power switching transistor</p> <p>X Multiplier diode</p> <p>Y High-power rectifier (diode)</p> <p>Z Zener diode</p>	<p>Three figures—serial codes used on devices for domestic and commercial applications</p> <p>One letter and two figures—serial codes used on devices for use in military, industrial, scientific, and pulse, equipment</p>

The third letter—if there is one—indicates industrial device and is a Y. If there is no third letter, the device is for consumer or entertainment use. The digits that follow the letters for industrial units indicate how many devices of that particular type have been registered. The digits start at 10 and go up to 99. When 99 is reached—i.e., after 89 devices—the last letter changes from a Y to an X and the numbering begins anew, working back towards A. There is no Z. For consumer devices, the numbers that follow the two letters start with 100, allowing registration of 899 similar devices.

FOR EXAMPLE: The designation BLY 80 means the device uses silicon (B) is for high rf power use (L), and is used in industrial applications, (Y); the 80 means that it is the 71st device of its type to be registered with Pro Electron.

CHARACTERISTICS OF INTEGRATED CIRCUIT LOGIC FAMILIES

	Typical Circuit Diagram	Logic Type	Relative Cost Per Gate	Propagation Time Per Gate (nsec)	Power Dissipation Per Gate (mW)	Typical Noise Margin (V)	Typical Fanin	Typical Fanout	Remarks
RTL Resistor-Coupled Transistor Logic		NOR	Low	15	10	0.2	3	3	Variations in input characteristics result in base-current "hogging" problem. Proper operation not always guaranteed. More susceptible to noise because of low operating and signal voltages.
RCTL Resistor-Capacitor Transistor Logic		NOR	Medium	50	10	0.2	3	4	Very similar to DCTL. Resistors resolve current "hogging" problem and reduce power dissipation. However, operating speed is reduced.
DCTL Direct-Coupled Transistor Logic		NOR	Med-high	30	10	0.2	3	4	Though capacitors can increase speed capability, noise immunity is affected by capacitive coupling of noise signals.
DTL Diode-Transistor Logic		NAND	Medium	25	15	0.7	8	8	Use of pull-up resistor and charge control technique improves speed capabilities. Many variations of this circuit exist, each having specific advantages.
TTL Transistor-Transistor Logic		NAND	Medium	10	20	1	8	12	Very similar to DTL. Has lower parasitic capacity at inputs. With the many existing variations, this logic family is very popular.
CTL Complementary Transistor Logic		OR/NOR	High	5	50	0.4	5	25	Similar to a differential amplifier, the reference voltage sets the threshold voltage. High speed, high-fanout operation is possible with associated high power dissipation. Also known as emitter-coupled logic (ECL).
CML Current-Mode Logic (ECL, Emitter-Coupled Logic)		AND/OR	High	5	50	0.4	5	25	More difficult manufacturing process results in compromises of active device characteristics and higher cost.
MOSL Metal-Oxide Semiconductor Logic		NOR	Very low	250	<1	2.5	10	5	Limited in switching speed compared to bipolar transistor circuits because the MOS transistor is a high-impedance device and cannot charge the stray circuit capacitance quickly.

CHARACTERISTICS OF DISPLAYS USED IN ELECTRONIC EQUIPMENT

<i>Display Technology</i>	<i>Average Viewing Angle</i>	<i>Typical Current Requirement</i>	<i>Typical Voltage Requirement</i>	<i>Typical Operating Temperatures</i>	<i>Relative Brightness</i>	<i>Durability</i>	<i>Colors available (basic light source)</i>
Light emitting diodes	Med. bright (washout in sunlight)	150° (magnifying lens cuts down angle)	5 to 10 mA	2 to 5V	-40 to 85°C	Rugged, no breakable parts	Red, orange, yellow, green
Liquid crystal displays	High contrast, no luminance	90 to 150°	50 to 500 μ A	3 to 7V	-10 to 65°C	Glass construction	Black on white (or reverse)
Gas discharge	Bright	100°	150mA to 2A	135 to 250V	0 to 70°C	Gas-filled glass construction	Orange
Incandescent	Very bright	150°	10 to 17 mA	3 to 5V	-55 to 100°C	Glass and filaments construction subject to shock	White, filterable to most colors
Vacuum fluorescent	Bright	100°	400 to 650 mA	30 to 50V	-10 to 55°C	Vacuum-tube device, glass construction	Bright-green filterable to many colors

(From *Electronic Products*, June, 1982, courtesy of Electronic Products.)

DEFINITIONS OF INTEGRATED CIRCUITS, LOGIC, AND MICROELECTRONICS TERMS

Abrading equipment This type of equipment fires a gas propelled stream of finely graded abrasive particles through a precise nozzle against the work surface. When linked to abrading equipment, it can cut intricate patterns in silicon semiconductors.

Abrasive trimming Trimming a film resistor to its nominal value by notching the resistor surface with a fine adjusted stream of abrasive material such as aluminum oxide.

Access time Time required in a computer to move information from memory to the computing mechanism.

Activating A treatment which renders nonconductive material receptive to electrodeless deposition.

Active elements Those components in a circuit which have gain or which direct current flow: diodes, transistors, SCR's, etc.

Active substrate A substrate for an integrated component in which parts display transistance. Examples are single crystals of semiconductor materials, within which transistors and diodes are formed.

A.D. converter Analog-to-digital converter; a circuit which accepts information in a continuously varying ac or dc current or voltage and whose output is the same information in digital form.

Adder Switching circuits which combine binary bits to generate the SUM and CARRY of these bits. Takes the bits from the two binary numbers to be added (ADDEND and AUGEND) plus the CARRY from the preceding less significant bit and generates the SUM and the CARRY.

Address Noun: a location, either name or number, where information is stored in a computer. Verb: to select or pick out the location of a stored information set for access.

Alloy junction A junction produced by alloying one or more impurity metals to a semiconductor. A small button of impurity metal is placed at each desired location on the semiconductor wafer, heated above its melting point, and cooled. The impurity metal alloys with the semiconductor material to form a *p* or *n* region, depending on the impurity used.

Alternate print In screen printing, one squeegee print stroke per substrate in alternate directions.

Alumina Aluminum oxide (Al_2O_3) used as a ceramic substrate material.

Align To put into proper relative position, agreement, or coordination when placing parts of a photomask together or placing a photomask over an etched pattern in the oxide on a semiconductor wafer.

Alignment The accuracy of coordination or relative position of images on a semiconductor oxide coating and on the photomask, or any other images placed in relation to those.

"AND" A boolean logic expression used to identify the logic operation wherein given two or more variables, all must be logical "1" for the result to be logical "1." The AND function is graphically represented by the dot (\cdot) symbol.

Angle of attack In screen printing, angle at which the squeegee blade attacks the screen surface.

Anticipated carry adder A parallel ADDER in which each stage is capable of looking back at all ADDEND and AUGEND bits of less significant stages and deciding whether the less significant bits provide a "0" or a "1" CARRY IN. Having determined the CARRY IN it combines it with its own ADDEND and AUGEND to give the SUM for that bit or stage. Also called FAST ADDER or look ahead CARRY ADDER.

Arrays Integrated circuits designed to perform near or actual subsystem operations. They are characterized by high complexity and component density. Each array package replaces a number of conventional I/Cs. Arrays are classified as medium-scale or larger-scale according to function performed. They can be monolithic or fabricated on a silicon wafer with interconnections between circuits.

Artwork The original pattern or configuration produced at an enlarged ratio, from which a circuit product is made, using a technique of photographic reduction to achieve microelectric scale; layouts and photographic films created to produce thick film screens and thin film masks.

As-fired Description of properties of ceramic substrates (smoothness) or thick film resistors (values) as they emerge from furnace processing, before any trimming or polishing.

Asynchronous inputs Those terminals in a flip-flop which can affect the output state of the flip-flop independent of the clock. Called Set, Preset, Reset or DC Set and Reset, or clear.

Back bonding Bonding active chips to the substrate using the back of the chip, leaving the face with its circuitry face up. The opposite is face down bonding.

Backfill Filling an evacuated hybrid circuit package with dry inert gas prior to hermetic sealing of the package.

Back-out Elevated temperature process which evaporates unwanted gases and moisture before final sealing of a hybrid circuit package.

Ball bond Type of thermocompression bond wherein a ball shaped end interconnect wire is flattened against a metallized pad.

Basic logic diagram A logic diagram that depicts logic functions with no reference to physical implementations. It consists primarily of logic symbols and is used to depict all logic relationships as simply and understandably as possible. Nonlogic functions are not normally shown.

Beam leads A generic term describing a system in which flat, metallic leads extend beyond the edges of a chip component, much the same as wooden beams extend from a roof overhang. These are used to interconnect the component to film circuitry.

Beryllia Beryllium oxide ceramics (BeO) significant in that they have high thermal conductivity characteristics.

Binders Substances added to unfired substrates and thick film compounds to add strength.

Binary coded decimal (BCD) A binary numbering system for coding decimal numbers in groups of 4 bits. The binary value of these 4-bit groups ranges from 0000 to 1001 and codes the decimal digits "0" through 9. To count to 9 takes 4 bits; to count to 99 takes two groups of 4 bits; to count to 999 takes three groups of 4 bits.

Binary logic Digital logic elements which operate with two distinct states. The two states are variously called true and false, high and low, on and off, or "1" and "0." In computers they are represented by two different voltage levels. The level which is more positive (or less negative) than the other is called the high level, the other the low level. If the true ("1") level is the most positive voltage, such logic is referred to as positive true or positive logic.

Bistable element Another name for flip-flop. A circuit in which the output has two stable states (output levels "0" or "1") and can be caused to go to either of these states by input signals, but remains in that state permanently after the input signals are removed. This differentiates the bistable element from a gate also having two output states but which requires the retention of the input signals to stay in a given state. The characteristic of two stable states also differentiates it from a monostable element which keeps returning to a specific state, and an astable element which keeps changing from one state to the other.

Bit A synonym for binary numeral. Also refers to a single binary numeral in a binary word.

Bleeding In photomasking, poor edge definition or acuity caused by spread of image onto adjacent areas.

Blister A lump or raised section of a conductor or resistor caused by out-gassing of the binder or vehicle during firing.

Boat A container for materials to be evaporated or fired.

Bond liftoff The failure mode whereby the bonded lead separates from the surface to which it was bonded.

Bond-to-bond distance The distance measured from the bonding site on the die to the bond impression on the post, substrate land, or fingers which must be bridged by a bonding wire or ribbon.

Bond-to-chip distance In beam lead bonding, the distance from the heel of the bond to the component.

Bonding pad A metallized area at the end of a thin metallic strip or on a semiconductor to which a connection is made. Also called Bonding Island.

Bonding ribbon and tape Bonding ribbon and tape are used in the manufacture of high-volume ICs such as memory devices and consumer products. Wire connections between I/O pads on the circuit die and the lead frame are replaced by a piece of tape with finely etched fingers that are patterned to fit exactly onto the pads.

Bonding wire Fine gold or aluminum wire for making electrical connections in hybrid circuits between various bonding pads on the semiconductor device substrate and device terminals or substrate lands.

Boolean algebra The mathematics of logic which uses alphabetic symbols to represent logical variables and "1" and "0" to represent states. There are three basic logic operations in this algebra: AND, OR, and NOT. (Also see NAND, NOR, Invert which are combinations of the three basic operations.)

Bubble memories In general, magnetic bubble memory systems consist of a film deposited on a garnet substrate. Data is stored in magnetic domains (bubbles) which are formed on the film by the application of a perpendicular magnetic field.

Buffer A circuit element, which is used to isolate between stages or handle a large fanout or to convert input and output circuits for signal level compatibility.

Bump chip A chip that has on its termination pads a bump of solder or other bonding material that is used to bond the chip to external contacts.

Bump contact A large area contact used for alloying directly to the substrate of a chip, for mounting or interconnecting purposes.

Buried layer A heavily doped (N+) region directly under the N doped epitaxial collector region of transistors in a monolithic integrated circuit used to lower the series collector resistance.

Burn-in Operation of electronic components often at elevated temperature, prior to their ultimate application in order to stabilize their characteristics and to identify their early failures.

Burn-in, dynamic High temp test with device(s) subject to actual or simulated operating conditions.

Burn-in, static High temp test with device(s) subjected to unvarying voltage rather than to operating conditions; either forward or reverse bias.

Camber In screen printing, a slight rise or curve in the surface of the substrate.

Carriage Mechanism on a screen printer to which the workholder is attached, which conveys the substrate to and from the print position.

Carriers Holders for electronic parts and devices which facilitate handling during processing, production, imprinting, or testing operations and protect such parts under transport.

Ceramic Non-metallic and inorganic material (e.g., alumina, beryllia, or steatite) used in microelectric substrates and component parts.

Cermet A combination of ceramic and metal powders used for thin and thick film resistors.

Chip A single substrate on which all the active and passive circuit elements have been fabricated using one or all of the semiconductor techniques of diffusion, passivation, masking, photoresist, and epitaxial growth. A chip is not ready for use until packaged and provided with external connectors. The term is also applied to discrete capacitors and resistors which are small enough to be bonded to substrates by hybrid techniques.

Chip and wire A hybrid technology exclusively employing face-up-bonded chip devices interconnected to the substrate conventionally, i.e., by flying wires.

Chip architecture The design or structure of an IC chip, incorporating arithmetic logic unit, registers, and control-bus pathway configuration.

Chip capacitors Discrete devices which introduce capacitance into an electronic circuit, made in tiny wedge or rectangular shapes to be fired onto hybrid circuits.

Chip component An unpackaged circuit element (active or passive) for use in hybrid microelectronics. Besides ICs, the term includes diodes, transistors, resistors, and capacitors.

Chip-outs Semiconductor die defects where fragments of silicon on the face have been chipped off in processing, leaving an active junction exposed.

Circuit The interconnection of a number of devices in one or more closed paths to perform a desired electrical or electronic function.

Clean room A work station or processing area in which steps are taken (e.g., air filtering) to protect incomplete circuits from dust and contamination.

Clear An asynchronous input. Also called Reset. To restore a memory element or flip-flop to a "standard" state, forcing the Q terminal to logic "0."

Clearance The shortest distance between the outer edges of images applied in sequence.

Clock A pulse generator which controls the timing of computer switching circuits and memory stages and regulates the speed at which the computer central processor operates. It serves to synchronize all operations in a digital system.

Clock input That terminal on a flip-flop whose condition or change of condition controls the admission of data into a flip-flop through the synchronous inputs and thereby controls the output state of the flip-flop. The clock signal performs two functions: (1) It permits data signals to enter the flip-flop; (2) after entry, it directs the flip-flop to change state accordingly.

CML (Current Mode Logic) Logic in which transistors operate in the unsaturated mode as distinguished from most other logic types which operate in the saturation region. This logic has very fast switching speeds and low logic swings. Also called ECL or MECL.

CMOS Complementary metal-oxide semiconductor. Device formed by the combination of a PMOS and an NMOS (P-type and N-type channel semiconductors).

Co-fire To place circuits onto an unfired ceramic and fire both circuits and ceramic simultaneously.

Collector junction The semiconductor junction in a transistor between the collector and base regions.

Collocator Device used to collect substrates from a screen printer and deposit them, in rows, onto a conveyor/dryer or furnace belt.

Compliant bond A bond which uses an elastically and/or plastically deformable member to import the required energy to the lead.

Component A packaged functional unit consisting of one or more circuits made up of devices, which (in turn) may be part of an operating system or subsystem. A part of, or division of, the whole assembly or equipment.

Component part A term sometimes used to denote a passive device.

Component placement equipment Automatic systems for sorting and placing components onto hybrid circuit substrates: consisting of indexing-conveyor, sorter, placement heads, missing component detector, programmable electro-pneumatic control, and options to handle special requirements.

Con/dryer Process equipment designed to receive screen printed substrates and dry the ink on the substrate while conveying them away.

Contact printing Print mode in screen printing wherein entire substrate contacts bottom surface of screen during print cycle. Necessary when using metal masks.

Contaminant An impurity or foreign substance present in a material that affects one or more properties of the material.

Cosmetic defect A variation from the conventional appearance of an item, such as a slight change in color: not necessarily detrimental to performance.

Corrosion In semiconductors, a defect in or on the aluminum metallization, usually a white crystalline growth.

Counter A device capable of changing states in a specified sequence upon receiving appropriate input signals. The output of the counter indicates the number of pulses which have been applied. (See also Divider.) A counter is made from flip-flops and some gates. The output of all flip-flops are accessible to indicate the exact count at all times.

Counter, binary An interconnection of flip-flops having a signal input so arranged to enable binary counting. Each time a pulse appears at the input, the counter changes state and tabulates the number of input pulses for readout in binary form. It has a 2^n possible counts where n is the number of flip-flops.

Counter, ring A special form of counter sometimes called a Johnson or shift counter which has very simple wiring and is fast. It forms a loop or circuits of interconnected flip-flops so arranged that only one is "0" and that as input signals are received, the positioning of the "0" state moved in sequence from one flip-flop to another around the loop until they are all "0," then the first one goes to "1" and this moves in sequence from one flip-flop to another until all are "1." It has $2 \times n$ possible counts where n is the number of flip-flops.

Cover lay, cover coat Outer layer(s) of insulating material applied over the conductive pattern on the surface of the substrate.

Crazing Minute cracks on or near the surface of materials such as ceramic.

Data Term used to denote facts, numbers, letters, symbols, binary bits presented as voltage levels in a computer. In a binary system data can only be "0" or "1."

DCTL (Direct-Coupled Transistor Logic) Logic employing only transistors as active circuit elements.

Debug To remove malfunctions from a system or device.

Decimal A system of numerical representation which uses ten numerals 0, 1, 2, 3,...,9. Each numeral is called a digit. A number system to the radix 10.

Defect Any deviation from the normally accepted characteristics of a product or component.

Delay The slowing up of the propagation of a pulse either intentionally, such as to prevent inputs from changing while clock pulses are present, or unintentionally as caused by transistor rise and fall time pulse response effects.

Detailed logic diagram A diagram that depicts all logic functions and also shows nonlogic functions, socket locations, pin numbers, test points, and other physical elements necessary to describe the physical and electrical aspects of the logic. The detailed logic diagram is used primarily to facilitate the rapid diagnosis and localization of equipment malfunctions. It also is used to verify the physical consistency of the logic and to prepare fabrication instructions. The symbols are connected by lines that represent signal paths.

Detritus Fragments of material produced during resistor trimming which remain in the trimmed area.

Device The physical realization of an individual electrical element in a physical independent body which cannot be further reduced or divided without destroying its stated function. This term is commonly applied to active devices. Examples are transistors, pnpn structures, tunnel diodes, resistors, capacitors, and inductors.

Diamond powders, grits, and compounds These materials are used mainly as abrasives for processes such as lapping and polishing, abrasives in abrasive trimming, or to create the cutting surface of slicing equipment.

Die A tiny piece of semiconductor material, broken from a semiconductor slice, on which one or more active electronic components are formed. (Sometimes called chip).

Die bonding Attaching the semiconductor chip to the substrate, with an epoxy, eutectic, or solder alloy.

Dielectric isolation The use of silicon dioxide barriers created during silicon IC processing to provide isolation between components on a chip.

Diffusion A process, used in the production of semiconductors, which introduces minute amounts of impurities into a substrate material such as silicon or germanium and permits the impurity to spread into the substrate. The process is very dependent on temperature and time.

Diffusion and oxidation systems Equipment in which non-conductive materials are made semiconductive by diffusing controlled amounts of selected impurities into the surface and the surface of silicon is oxidized selectively to provide a protective or insulative layer. Diffusion and oxidation are accomplished by exposing the silicon wafer to specific atmospheres in a high temperature furnace.

Diffusion depth testing A diffusion depth tester determines to what depth diffused impurities have been implanted into a wafer under ion implantation.

Digital circuit A circuit which operates in the manner of a switch, that is, it is either "on" or "off." More correctly should be called a binary circuit.

Diode A device permitting current to flow in one direction only. Diodes are used in logic circuits to control the passage or nonpassage of a signal from one element to another.

Discrete Having an individual identity. Fabricated prior to installation, and/or separately packaged, not part of an integrated circuit.

DIP Dual in-line package.

Discrete circuits Electronic circuits built of separate, individually manufactured, tested, and assembled diodes, resistors, transistors, capacitors, and other specific electronic components.

Discrete component A circuit component having an individual identity, such as a transistor, capacitor, or resistor.

Divider (Frequency) A counter which has a gating structure added which provides an output pulse after receiving a specified number of input pulses. The outputs of all flip-flops are not accessible.

Dopants Selected impurities introduced into semiconductor substrates in controlled amounts, the atoms of which form negative (n-type) and positive (p-type) conductive regions. Phosphorus, arsenic, and antimony are n-type dopants for silicon; boron, aluminum, gallium, and indium are p-type dopants for silicon.

Doping Addition of controlled impurities to a non-conductive material to achieve the desired semiconductor characteristic, accomplished through thermal diffusion or ion implantation.

Dot "AND" Externally connecting separate circuits or functions so that the combination of their outputs results in an "AND" function. The point at which the separate circuits are wired together will be a "1" if all circuits feeding into this point are "1" (also called WIRED "OR").

Dot "OR" Externally connecting separate circuits or functions, so that the combination of their outputs results in an "OR" function. The point at which the separate circuits are wired together will be a "1" if any of the circuits feeding into this point are "1."

Driver An element which is coupled to the output stage of a circuit in order to increase its power or current handling capability or fanout; for example, a clock driver is used to supply the current necessary for a clock line.

DTL (Diode-Transistor Logic) Logic employing diodes with transistors used only as inverting amplifiers.

Dual-in-line package (DIP) Carrier in which a semiconductor integrated circuit is assembled and sealed. Package consists of a plastic or ceramic body with two rows of seven vertical leads which are inserted into a circuit board and secured by soldering.

Durometer An instrument for measuring the hardness of the squeegee material for screen printing.

ECL Emitter-coupled logic; a type of current mode logic in which the circuits are coupled with one another through emitter followers at the input or output of the logic circuit.

Ejection Wipe off or removal of the printed part from the workholder, in screen printing.

Electrical element The concept in uncombined form of the individual building blocks from which electric circuits are synthesized.

Electron beam bonding Process using a stream of electrons to heat and bond two conductors within a vacuum.

Electron beam lithography Lithography in which the radiation sensitive film or resist is placed in the vacuum chamber of a scanning beam electron microscope and exposed by an electron beam under digital computer control.

Electron beam welding Process in which welder generates a stream of electrons traveling at up to 60% of the speed of light, focuses it to a small, precisely controlled spot in a vacuum, and converts the kinetic energy into extremely high temperature on impact with the workpiece.

Emitter The region of transistor from which charge carriers (minority carriers in the base) are injected into the base.

Enable To permit an action or the acceptance or recognition of data by applying appropriate signals (generally a logic "1" in a positive logic) to the appropriate input. (See Inhibit.)

Encapsulate To embed electronic components or other entities in a protective coating, usually done when the plastic encapsulant is in fluid state so that it will set in solid form as an envelope around the work.

Entrapment The damaging admission and trapping of air, flux, and fumes, caused by contamination and plating process defects.

Epitaxial Pertaining to a single-crystal layer on a crystalline substrate, and having the same crystalline orientation as the substrate: e.g., silicon atoms condensed from vapor phase onto a silicon-wafer substrate.

Epitaxial growth A process of growing layers of material on a selected substrate. Usually silicon is grown in a silicon substrate. Silicon and other semiconductor materials may be grown on a substrate with compatible crystallography, such as sapphire (silicon-on-sapphire).

Epitaxial layer A precisely doped, thin layer of silicon grown on a p-doped thick wafer and into which n-type semiconductor junctions are diffused.

EPROM Electrically programmable read only memory.

Etch factor The ratio of depth of etch to the amount of undercut.

Exclusive "OR" A logical function whose output is "1" if either of the two variables is "1" but whose output is "0" if both inputs are "1" or both are "0."

Exposure The act of subjecting photosensitive surfaces or matter to radiant energy such as light to produce an image.

Evaporation and sputtering materials Metals used for evaporation charges and sputtering targets, including: *chromium* and its alloys, for (1) a thin adhesive layer on IC substrates to allow better deposition of gold or other metal, (2) resistor material, and (3) vacuum deposition in mask production; *aluminum* and certain Al alloys, for first layer deposition in MOS technology; *molybdenum*, as a conductor or adhesive layer for IC fabrication; and *titanium*, as an intermediate adhesive layer for beam-lead interconnection.

Evaporation sources Boats and filaments used as heat sources for vacuum evaporation to form thin film layers on substrates. The process is frequently done by resistively heating the evaporant in a ceramic crucible or by self-heating or boats constructed of tungsten, molybdenum, or tantalum.

Extrinsic properties Properties introduced into a semiconductor by impurities with a crystal.

Extrinsic semiconductor The resulting semiconductor produced when impurities are introduced into an otherwise non-semiconductor crystal. The electrical properties depend upon the impurities.

Face bonding Process of bonding semiconductor chip so that its circuitry side faces the substrate. Flipchip and beam lead bonding are two common methods. (Opposite of back bonding.)

Fall time A measure of the time required for the output voltage of a circuit to change from a high voltage level to a low voltage level once a level change has started. Current could also be used as the reference, that is, from a high current to a low current level.

Fanin The number of inputs available to a specific logic stage of function.

Fanout The number of input stages that can be driven by a circuit output.

Fast ADDER (See Anticipated CARRY ADDER.)

FEB (Functional Electronic Block) Another name for a monolithic integrated circuit of thick-film circuit.

Feedback When part of the output of a circuit is channeled back to an input, it is said to have feedback. When part of the output of an amplifier is routed back to augment the input signal, the amplifier has positive feedback or if this rechanneling is employed to diminish the input it is called negative feedback.

FET Field effect transistor; semiconductor device in which resistance between source and drain terminals is modulated by a field applied to the third (gate) terminal.

Film conductor Electrically conductive material formed by deposition on a substrate.

Film microcircuit Thin or thick film network forming an electrical interconnection of numerous devices.

Film resistor A device whose resistive material is a film on an insulator substrate; resistance value is determined by trimming.

Final seal The hybrid microelectronic packaging step which encloses the circuit so that further internal processing cannot be performed without disassembly.

Flatpack Subassembly composed of two or more stages made up of integrated circuits and thin film components mounted

on a ceramic substrate. This semiconductor network is enclosed in a shallow rectangular package with the connecting leads projecting from edges of the package.

Flip-chip A generic term describing a semiconductor device having all terminations on one side of the form of bump contacts. After the surface of the chip has been passivated or otherwise treated, it is flipped over for attaching to a matching substrate.

Flip-flop (storage element) A circuit having two stable states and the capability of changing from one state to another with the application of a control signal and remaining in that state after removal of signals. (See Bistable element.)

Flip-flop, "D" D stands for delay. A flip-flop whose output is a function of the input which appeared one pulse earlier; for example, if a "1" appeared at the input, the output after the next clock pulse will be a "1."

Flip-flop, "J-K" A flip-flop having two inputs designated J and K. At the application of a clock pulse, a "1" on the "J" input and a "0" on the "K" input will set the flip-flop to the "1" state; a "1" on the "K" input and a "0" on the "J" input will reset it to the "0" state; and "1"s simultaneously on both inputs will cause it to change state regardless of the previous state. J = 0 and K = 0 will prevent change.

Flip-flop, "R-S" A flip-flop consisting of two cross-coupled NAND gates having two inputs designated "R" and "S." A "1" on the "S" input and "0" on the "R" input will reset (clear) the flip-flop to the "0" state, and "1" on the "R" input and "0" on the "S" input will set it to the "1." It is assumed that "0"s will never appear simultaneously at both inputs. If both inputs have "1"s it will stay as it was. "1" is considered nonactivating. A similar circuit can be formed with NOR gates.

Flip-flop, "R-S-T" A flip-flop having three inputs, "R," "S," and "T." This unit works as the "R-S" flip-flop except that the "T" input is used to cause the flip-flop to change states.

Flip-flop, "T" A flip-flop having only one input. A pulse appearing on the input will cause the flip-flop to change states. Used in ripple counters.

Floating squeegee This squeegee, as opposed to a rigid squeegee, has the ability to produce a rocking movement on the horizontal plane in screen printing.

Flood stroke Return stroke of squeegee in screen printing which redistributes ink back over the pattern. Provides for proper ink control, and is especially useful for thixotropic inks. (See "Print Stroke".)

Fluid flow masking A gold electro-plating technique in which the work to be plated is the cathode and current flows through the fluid stream of plating material, allowing control of deposit at the point of contact between the stream and the workpiece.

Furnaces, diffusion and firing Systems designed for enclosed elevated temperature processing of solid state devices and systems, in gaseous atmospheres. Diffusion furnaces are operated at temperatures from 1,000 to 1300°C to achieve doping of semiconductor substrates, by one of a number of processes. Oxidation is a process that puts a protective layer of silicon oxide on the wafer and is used either as an insulator or to mask out certain areas when doping. Deposition systems, of which there are three (liquid, gaseous, solid), are used to deposit impurities on the silicon wafer. Other systems include a drive-in system used to diffuse impurities into the wafer to a specified level, and an alloy system which is used in a final step of the metallization process. Firing furnaces are used for the curing of multilayer ceramics for integrated electronics and for the firing of thick film materials on microcircuits.

Furnace, screen printing Process equipment designed to cure substrates after screen printing and drying.

FULL ADDER See Adder.

Gate 1. A circuit having an output and a multiplicity of inputs designed so that the output is energized only when a certain combination of pulses is present at the inputs. An AND-gate delivers an output pulse only when every input is energized simultaneously in a specified manner. An OR-gate delivers an output pulse when any one or more of the pulses meet the specified conditions. 2. An electrode in a field effect transistor. 3. A circuit that admits and amplifies or passes a signal only when a gating (triggering) pulse is present. 4. A circuit in which one signal serves to switch another signal on and off.

Gate definitions below assume positive logic

Gate, AND All inputs must have "1" level signals at the input to produce a "1" level output.

Gate, NAND All inputs must have "1" level signals at the input to produce a "0" level output.

Gate, NOR Any one input or more than one input having a "1" level signal will produce a "0" level output.

Gate, OR Any one input or more than one input having a "1" level signal will produce a "1" level output.

Gates (decision elements) A circuit having two or more inputs and one output. The output depends upon the combination of logic signals at the input.

Germanium polycrystalline A prime raw material for making crystal ingots.

Glassivation A deposited layer of glass on top of a metallized wafer or chip; primarily a protective layer.

Glazed substrate Ceramic substrate with a glass coating to effect a smooth and nonporous surface.

Green ceramic Unfired ceramic material.

Green substrate Unfired material in substrate form. Normally substrates are printed after firing. Under special circumstances, however, green (unfired) substrates are printed.

Half ADDER A switching circuit which combines binary bits to generate the SUM and the CARRY. It can only take in the two binary bits to be added and generate the SUM and CARRY (see also ADDER).

Half shift register Another name for certain types of flip-flops when used in a shift register. It takes two of these to make one stage in a shift register.

Header Base of a hybrid circuit package, holding the leads.

High See Binary logic.

High temperature reverse bias Burn-in type test of diodes and transistors conducted with the junctions reverse biased to effect any failure due to ion migration in bonds of dissimilar metals

Hole A mobile vacancy or electron deficiency in the valence structure of a semiconductor. It is equivalent to a positive charge.

HTRB High temperature reverse bias.

Hybrid A method of manufacturing integrated circuits by using a combination of monolithic, thin-film and thick-film techniques.

IC Integrated circuit.

IC socket Female contact which provides pluggable electrical engagement on its inner surface for integrated circuit components to achieve interfacing to a PCB.

Image/pattern The printed screen or design on the substrate after screen printing.

Inhibit To prevent an action, or acceptance of data, by applying an appropriate signal to the appropriate input (generally a logic "0" in positive logic). (See Enable.)

Ink In hybrid technology the conductive paste used on thick film materials to form the printed conductor pattern. Usually contains metals, metal oxide, glass frit, and solvent.

Input/output Interface circuits or devices offering access between external circuits and the central processing unit or memory.

Integrated circuit (EIA definition) (1) "The physical realization of a number of electrical elements inseparably associated on or within a continuous body of semiconductor material to perform the functions of a circuit." (See Slice and Chip.) (2) Electronic circuits or systems consisting of an interconnected array of extremely small active and passive elements, inseparably associated on or within a continuous substrate or body. Other names are *integrated electronic circuit*, *integrated electronic system*, and *integrated microcircuit*.

Integrated injection logic Integrated circuit logic which uses bipolar transistor gates. Makes possible large scale integration on silicon for logic arrays and other analog and digital applications.

Inverter A circuit whose output is always in the opposite state from the input. This is also called a NOT circuit. (A teeter-totter is a mechanical inverter.)

I/O Input/output.

Ion implantation Precise and reproducible method of doping semiconductors to achieve a desired characteristic. Ions of the particular dopant are energized and accelerated to the point where they can be driven in a focused beam directly into the silicon wafer. This technique assures uniform, accurately controlled depth of implantation and ionic diffusion in the wafer.

Ion milling Ion milling is a VLSI production technique that performs many of the same type of tasks that more traditional wet chemical and plasma etching processes do.

ISHM The International Society for Hybrid Microelectronics.

Isolation diffusion In MIC technology, the diffusion step which generates back-to-back junctions to isolate active devices from one another.

Josephson effect The tunneling of electron pairs through a thin insulating barrier between two superconducting materials.

Junction A joining of two different semiconductors or of semiconductor and metal. Alloy, diffused, electrochemical, and grown are the four junction types.

Kerf The slit or channel cut in a resistor during trimming by laser beam of abrasive jet.

Laminar flow A directed stream of filtered air moved constantly across a clean work station, usually parallel to the workbench surface.

Land area in image Closed spaces in the screen which result in open spaces on the printed image in screen printing.

Lapping Grinding and polishing such products as semiconductor blanks in order to obtain precise thicknesses or extremely smooth, flat, polishing surfaces.

Large-scale integration (LSI) Usually denotes arrays of integrated circuits on a single substrate that comprise 100 or more individual active circuit functions or gates.

Laser bonding A process which forms a metal-to-metal fastened union, using a laser heat source to join conductors.

Laser trim The adjustment (upward) of a film resistor value by applying laser from a focused laser source to remove material.

Laser welding Process in which thermal energy released by a laser impinging upon the surface of a metal is conducted into the bulk of the metal work-piece by thermal conduction, bonding component leads to highly conductive materials such as copper printed circuitry.

Lead frame The metal part of a solid state device package which achieves electrical connection between the die and other parts of the systems of which the IC is a component. Large scale integrated circuits are welded onto lead frames in such a way that leads are available to facilitate making connections to and from the various solid state devices to the packages.

Leadless inverted device (LID) A shaped, metallized ceramic form used as an intermediate carrier for the semiconductor chip devices, especially adapted for attachment to conductor lands of a thick or thin film network by reflow solder bonding.

Leak detectors Applied only to hermetic devices, fine leak detectors are used to detect defects in sealing that are too small to be detected by gross-leak methods. Devices are placed in a bomb pressurized with a mixture of gases.

LID Leadless inverted device.

Life aging Burn-in test which moderates the elevation of temperature and extends the time period in order to test overall device quality as opposed to infant mortality.

Linear circuit A circuit whose output is an amplified version of its input, or whose output is a predetermined variation of its input.

Logic A mathematical arrangement using symbols to represent relationships and quantities, handled in a microelectronic network of switching circuits or gates, which perform certain functions; also, the type of gate structure used in part of a data processing system.

Logic diagram A picture representation for the logical functions of AND, OR, NAND, NOR, NOT.

Logic function A combinational, storage, delay, or sequential function expressing a relationship between variable signal input(s) to a system or device and the resultant output(s).

Logic swing The voltage difference between the two logic levels "1" and "0."

Logic symbol The graphic representation of the aggregate of all the parts implementing a logic function.

Low See Binary logic.

LSI Large scale integration.

Magnetic integrated circuit The physical realization of one or more magnetic elements inseparably associated to perform all, or at least a major portion, of its intended function.

Masks, microelectronic Thin metals or other materials with an open pattern designed to mask off or shield selected portions of semiconductors or other surfaces during deposition processes. There also are photomasks or optical masks for contact or projection printing of wafers—these may use an extremely flat glass substrate with iron oxide, chrome, or emulsion coating. There also are thick film screen masks.

Medium scale integration (MSI) The physical realization of a microelectronic circuit fabricated from a single semiconductor integrated circuit having circuitry equivalent to more than 10 individual gates or active circuit functions.

Memory The semi-permanent storage of numbers, in digital form, in a circuit or system. With reference to computers, the term also describes the storage capability or location and which receives and holds information for later use. Also, the storage arrangement, such as RAM or other type.

Metalization The selective deposition of metal film on a substrate to form conductive interconnection between IC elements and points for connections with the outside world.

Metal-oxide-semiconductor (MOS) A metal over silicon oxide over silicon arrangement which produces circuit components such as transistors. Electrical characteristics are similar to vacuum tubes.

MIC Monolithic integrated circuit.

Microbond The realization of a very small fastened joint between conductors or between a conductor and a microelectronic chip device.

Microcircuit The physical realization of a hybrid or monolithic interconnected array of very small active and passive electronic elements.

Microelectronics The entire spectrum of electronic art dealing with the fabrication of sophisticated, practical systems using miniaturized electronic components. Microelectronics has developed along two basic technologies—monolithic integrated circuits and hybrid integrated circuits.

Microminiaturization The process of packaging an assembly of microminiature active and passive electronic elements, replacing an assembly of much larger and different parts.

Micromodule A microcircuit constructed of a number of components (e.g., microwafers) and encapsulated to form a block that is still only a fraction of an inch in any dimension.

Microprobe An extremely sharp and small exploring tool head attached to a positioning handle, used for testing microelectronic circuits by establishing ohmic contact.

Microprocessor An IC package incorporating logic, memory, control, computer, and /or interface circuits, the whole of which is designed to handle certain functions.

Microwave integrated circuit The physical realization of an electronic circuit operating at frequencies above one gigahertz and fabricated by microelectronic techniques. Either hybrid or monolithic integrated circuit technology may be utilized.

Minority carrier The less-predominant carrier in a semiconductor. Electrons are the minority in p-type; holes are the minority in n-type semiconductors.

Mobility The ease with which charge carriers can move through a semiconductor. Generally electrons and holes do not have equal mobility in a given semiconductor. Mobility is higher in germanium than in silicon.

Module A packaging unit displaying regularity and separable repetition. It may or may not be separable from other modules after initial assembly. Usually all major dimensions are in accordance with a prescribed set of dimensions.

Molecular beam epitaxy equipment This equipment is used for growing epitaxial thin films under UHV conditions by directing beams of atoms or molecules created by thermal or electron beam evaporation onto clean, heated substrates.

Molecular electronics Simply, electronics on a molecular scale, dealing with the production of complex circuitry in semiconductor devices with integral elements processed by growing multi-zoned crystals in a furnace for the ultimate performance of electrical functions.

Monolithic Refers to the single silicon substrate in which an integrated circuit is constructed. (See Integrated circuit.)

Monolithic integrated circuit The physical realization of electronic circuits or sub-systems from a number of extremely small

circuit elements inseparably associated on or within a continuous body or a thin film of semiconductor material.

Morphology, integrated The structural characterization of an electronic component in which the identity of the current or signal modifying areas, patterns, or volumes has become lost in the integration of electronic materials, in contrast to an assembly of devices performing the same function.

Morphology, translational The structural characterization of an electronic component in which the areas or patterns of resistive, conductive, dielectric, and active materials in or on the surface of the structure can be identified in a one-to-one correspondence with devices assembled to perform an equivalent function.

MOS Metal-oxide-semiconductor. A technology for producing transistors that incorporates metal over oxide over silicon layers. Electrical characteristics are similar to vacuum tubes.

MSI Medium scale integration.

MTNS Metal thick nitride semiconductor, which is similar to an MTOS device except that a thick silicon nitride or silicon nitride-oxide layer is used instead of just plain oxide.

MTOS Metal thick oxide semiconductor, where the oxide outside the desired active gate area is made much thicker in order to reduce problems with unwanted parasitic effects.

Multichip integrated circuit Hybrid integrated circuit which includes two or more SIC, MSI, or LSI chips.

Multilayer dielectric A compound including glass and ceramic which is applied as an insulating barrier between conductors for multi-layer and crossover work.

"NAND" A Boolean logic operation which yields a logic "0" output when all logic input signals are logic "1."

Negative logic Logic in which the more negative voltage represents the "1" state; the less negative voltage represents the "0" state. (See Binary logic.)

Network A collection of elements, such as resistors, coils, capacitors, and sources of energy, connected together to form several interrelated circuits.

NMOS N-channel MOS circuits, using currents made up of negative charges and producing devices at least twice as fast as PMOS.

Noble metal paste A soft, moist, smooth compound made up partially of precious metals such as gold, platinum, ruthenium, or others classed as noble metals, providing conductors in film circuitry.

Noble system Thick film system using conductors of gold, platinum, and possibly palladium silver, or certain alloys of these precious metals.

Noise immunity A measure of the insensitivity of a logic circuit to triggering or reaction to spurious or undesirable electrical signals or noise, largely determined by the signal swing of the logic. Noise can be either of two directions, positive or negative.

Non-noble system Thick film system using conductors of copper, tungsten, nickel, molybdenum, and other non-noble metals.

"NOR" A Boolean logic operation which yields a logic "0" output with one or more true "1" input signals.

"NOT" A Boolean logic operation indicating negation, not "1." Actually an inverter. If inputs is "1" output is NOT "1" but "0." If the input is "0" output is NOT "0" but "1." Graphically represented by a bar over a Boolean symbol such as A. A means "when A is not 1."

n-Region The zone in a semiconductor in which electron density is greater than hole density.

n-type semiconductor Semiconductor material whose impurities produce free electrons in the compound, leading to conduction.

Off-contact printing An extrinsic semiconductor in which electron density exceeds hole density. An electron donor type. Print mode wherein screen printer's squeegee stretches screen to touch the substrate and deposit ink. Usually 0.010" snap-off is used. Allows thicker ink deposition.

Offset The change in input voltage required to produce a zero output voltage in a linear amplifier circuit. In digital circuits it is the dc voltage on which a signal is impressed.

One ("1") See Binary Logic.

"OR" A Boolean logic operation used to identify the logic operation wherein two or more true "1" inputs only add to one true "1" output. Only one input needs to be "true" to produce a "true" output. The graphical symbol for "OR" is a plus sign (+).

Overglaze A glass compound in low-melting, vitreous form, used as a coating to passivate thick film resistors and offer mechanical protection.

Overlap The contact area between a film resistor and film conductor.

Packaging The process of physically locating, connecting, and protecting devices or components.

Packaging density The number of devices or equivalent devices per unit volume in a working system or subsystem.

Pad In IC technology, the bonding area.

Parallel gap welding Type of resistance welding wherein electrodes contact the work from one side only. Mechanism by which bonding occurs is virtually always fusion. Process is well suited to welding component leads to planar surfaces such as IC leads to PC conductors.

Parallelity Relationship of screen to work-holder and print head in screen printing. Each should be parallel to one another in order to print accurately.

Parameter Any specific characteristic of a device. When considered together, all the parameters of a device describe its operational and physical characteristics.

Parallel This refers to the technique for handling a binary data word which has more than one bit. All bits are acted upon simultaneously. It is like the line of a football team. Upon a signal all line men act. (See also Serial.)

Parallel Adder A conventional technique for adding where the two multibit numbers are presented and added simultaneously (parallel). A ripple adder is still a parallel adder; the carry is rippled from the least significant to the most significant bit. Another type of parallel adder is the "Look Ahead," or "Anticipated Carry" adder. (See Ripple ADDER and Fast ADDER.)

Parallel operation The organization of data manipulation within computer circuitry where all the digits of a word are transmitted simultaneously on separate lines in order to speed up operation, as opposed to serial operation.

Particle impact noise detection (PIND) PIND testing equipment detects any loose foreign particles that may be present in a hermetic package. The package is placed on a shaker table where it is in intimate contact with an acoustic transducer that drives an ultrasonic amplifier.

Parts handling Devices used to load and unload substrates during screen printing and drying operations.

Passivation The growth of an insulating layer on the surface of a semiconductor to provide electrical stability by isolating the transistor surface from electrical and chemical conditions in the environment. It reduces reverse-current leakage, increases breakdown voltages, and improves the power-dissipation rating.

Passive elements Resistors, inductors, or capacitors, elements without gain.

Passive substrate A substrate for an integrated component which may serve as physical support and thermal link to a thick- or thin-film integrated circuit, but which exhibits no transistances. Examples of passive substrates are glass, ceramic, and similar materials.

Paste Synonymous with "composition" and "ink" when relating to screenable, thick film materials.

Pattern/image The open area in the screen through which the ink penetrates to become the printed image on the substrate, in screen printing.

Photomask A square, flat glass substrate, coated with a photographic emulsion or a very thin layer of metal, on which appear several hundred circular pattern patterns (each containing thousands of images). The patterns are exposed onto semiconductor wafers.

Photoresists and processing materials These are light sensitive materials that are deposited as a uniform film on a wafer or substrate. The exposure of specific pattern is performed through masking operations.

Pinhole A minute hole through a layer or pattern.

Planar process Fabrication of MICs and semiconductor devices using silicon dioxide as a masking agent and producing components on a single plane.

Platen Plate which holds substrate during screen printing.

Plating The deposition of a metal layer on a substrate surface by electrolytical or certain chemical means. The materials include gold, copper, solder, etc. The functions of the metal plate vary, including corrosion protection, solderability enhancement, etch resist, bonding for lead frames, and electrical connection, among others.

PMOS P-channel MOS: refers to the oldest type of MOS circuit where the electrical current is a flow of positive charges.

Polishing A mechanical finishing operation conducted upon solid state substrates to achieve smoothness and desired surface qualities. See *Lapping*.

Porcelainize To coat and fire a metal with glass material, forming a hybrid circuit substrate.

Positive logic Logic in which the more positive voltage represents the "1" stage. (See Binary logic.)

Preset An input like the Set input and which works in parallel with the Set.

Probing A term used to describe electrical testing that employs very finely-tipped probes applied sequentially to each of the finished dice of a wafer.

PROM Programmable read-only memory; a ROM which requires a programming operation.

Propagation delay A measure of the time required for a change in logic level to be transmitted through an element or a chain of elements.

Propagation time The time necessary for a unit of binary information (high voltage or low) to be transmitted or passed from one physical point in a system or subsystem to another. For example, from input of a device to output.

p-type semiconductor An extrinsic semiconductor in which the hole density exceeds the conduction electron density. An electron acceptor type.

Print stroke Stroke of the squeegee in screen printing at which time ink is forced through the pattern on the screen.

Print-print Squeegee prints in both directions per substrate in screen printing process.

Printer Process unit designed to accept, hold, and screen print a substrate in order that ink may be applied with extremely accurate and repeatable registration.

Pulse A signal of very short duration.

Purple plague Defect-causing formation of gold-aluminum chemical compounds often produced when gold and aluminum are bonded. Purple in color, brittle, subject to degenerative failure, and sometimes compounded by inclusion of silicon.

Q output The reference output of a flip-flop. When this output is "1" the flip-flop is said to be in the "1" state; when it is "0" the output is said to be in the "0" state. (See also State and Set.)

Q output The second output of a flip-flop. It is always opposite in logic level to the Q output.

RAM Random access memory; a type of memory which offers access to storage locations within it by means of X and Y coordinates.

RCTL (Resistor-Capacitor-Transistor-Logic) Same as RTL except that capacitors are used to enhance switching speed.

Register A device which can store information, usually that contained in a small subset or word of the total within a digital computer system.

Registration The degree of proper alignment of a circuit pattern on the substrate.

Resist Material such as ink, paint, or metallic plating, used to protect the desired portions of the printed conductive pattern from the action of the etchant, solder, or plating.

Reset Also called clear. Similar to Set except it is the input through which the Q output can be made to go to "0."

Rigid squeegee Firm mounting of the screen printer squeegee blade and holder. Squeegee adjustment is more critical.

Ripple The transmission of data serially. It is a serial reaction analogous to a bucket brigade or a row of falling dominoes.

Ripple ADDER A binary adding system similar to the system most people used to add decimal numbers—that is, add the "units" column, get the carry, add it to the "10's" column, get the carry, add it to the "100's" column, and so on. Again it is necessary to wait for the signal to propagate through all columns even though all columns are present at once (parallel). Note that the carry is rippled.

Ripple counter A binary counting system in which flip-flops are connected in series. When the first flip-flop changes it effects the second which effects the third and so on. If there are ten in a row, the signal must go sequentially from the first flip-flop to the tenth.

Risers In a multilayer substrate, the conductive paths that vertically connect various levels.

Rotary (theta) motion Angular (rotary) adjustment of image to substrate. Allows registration in angularity in addition to "X" and "Y" in screen printing. (Also called Theta motion.)

Rise time A measure of the time required for the output voltage of a state to go from a low voltage level ("0") to a high voltage level ("1") once a level change has been started.

ROM Read-only memory; a random access storage in which the data pattern is unchangeable after manufacture.

RTL (Resistor-Transistor-Logic) Logic is performed by resistors. Transistors are used to produce an inverted output.

Sapphire substrates Materials which provide a uniform dielectric constant, controlled orientation, thermal conductivity, and the single crystal surface desired for SOS, hybrid IC, and other microcircuit systems. The material may be grown directly in ribbons, tubes, filaments, and sheets.

Screen Tensioned mesh material with an open pattern through which ink penetrates to place an image on the substrate. Screen is above and parallel to the substrate during screen printing.

Screen printing, thick film The art of depositing conductive, resistive, and insulating materials on a dielectric base. This deposition is made through selected open areas in screens with inks or pastes forced through the open areas of the screen by squeegee motion onto the substrate base. In some cases, masks instead of conventional mesh screens may be used.

Scribing Scratching a tooled line or laser path on a brittle substrate to allow a wafer to be clef or broken along the line, producing IC chips when all brakes are completed.

Scribing machines and tools Equipment used to separate wafers into individual devices, chips, or dice. This has been done by crude techniques similar to glass cutting, but is now accomplished by more efficient methods, using truncated pyramid diamond scribes, automated machines, conical tools, or lasers.

SEM Standard electronic module; a subassembly configuration format which meets a particular U.S. Navy set of specifications. This abbreviation is also used for scanning electron microscope.

Semiconductor The name applied to materials which exhibit relatively high resistance in a pure state but much lower resistance when minute amounts of impurities are added. The word is commonly used to describe electronic devices made from semiconductor materials.

Semiconductor devices Devices in which the characteristic distinguishing electron conduction takes place within a semiconductor, ranging from the single unit transistor to multiple unit devices such as the semiconductor rectifier. Other devices are diodes, photocells, thermistors, and thyristors.

Semiconductor integrated circuit (SIC) The physical realization of a number of electric elements inseparably associated on or within a continuous body of semiconductor material to perform the function of a circuit.

Serial The technique for handling a binary data word which has more than one bit. The bits are acted upon one at a time. It is like a parade going by a review point.

Serial operation The organization of data manipulation within computer circuitry where the digits of a word are transmitted one at a time along a single line. The serial mode of operation is slower than parallel operation, but utilizes less complex circuitry.

Set An input on a flip-flop not controlled by the clock (see Asynchronous inputs), and used to effect the Q output. It is this input through which signals can be entered to get the Q output to go to "1." Note it cannot get Q to go to "0."

Shear tester Shear testers are used to determine the integrity of a material or to test the adherence between two attached items. It is used for testing eutectic and epoxy die-bond strengths, and for adherence testing a gold-wire ball bonds, gold and solder chip bumps, external lead frames, coined and welded gold electrical contacts, thick film plating, and more.

Shift The process of moving data from one place to another. Generally many bits are moving at once. Shifting is done synchronously and by command of the clock. An 8-bit word can be shifted sequentially (serially)—that is, the 1st bit goes out, 2nd bit takes 1st bit's place, 3rd bit takes 2nd bit's place, and so on, in the manner of a bucket brigade. Generally referred to as shifting left or right. It takes 8 clock pulses to shift an 8-bit word or all bits of a word can be shifted simultaneously. This is called parallel load or parallel shift.

Shift register An arrangement of circuits, specifically flip-flops, which is used to shift serially or in parallel. Binary words are generally parallel loaded and then held temporarily or serially shifted out.

SIC Semiconductor integrated circuit.

Silicon A brittle, gray, crystalline chemical element which, in its pure state, serves as a semiconductor substrate in microelectronics. It is naturally found in compounds such as silicon dioxide.

Silicon gate A type of MOS in which the gate is made of silicon instead of metal. It is faster and denser than the metal-gate MOS.

Silicon nitride A compound of silicon and nitrogen deposited on the surface of silicon monolithic ICs to impart greater stability.

Silicon oxide Silicon monoxide or dioxide or a mixture, the latter of which can be deposited on a silicon IC as insulation between metallization layers.

Single print One squeegee print stroke and flood return per substrate, in screen printing.

Skewing Refers to time delay or offset between any two signals in relation to each other.

Slewing rate Rate at which the output can be driven from limit to limit over the dynamic range.

Slice A single wafer cut from a silicon ingot forming a thin substrate on which all active and passive elements for multiple integrated circuits have been fabricated utilizing semiconductor epitaxial growth, diffusion, passivation, masking, photo resist, and metallization technologies. A completed slice generally contains hundreds of individual circuits. (see Chip.)

Small scale integration A circuit of under 10 gates, generally involving one metallization level implementing one circuit function in monolithic silicon.

Snap-off Distance from top of substrate in screen printing to bottom surface of screen. Squeegee must stretch screen this far to meet the substrate and deposit ink. Set by "Z" motion adjustments.

Snipstrate Scored large area substrate which, after screen printing, may be snapped or broken apart into smaller sized substrates.

Snugger Device for automatically positioning and holding the substrate in proper position during the print cycle, in screen printing.

Solder systems for bonding and welding Processors for ceramic hybrid microcircuits, substrates, lead frames, microassemblies, flat packs, wire memory arrays, ceramic headers, and magnet wire, where solder normally has been pretinned on the substrate or individual components, or solder pastes provide solder without the need for pretinning operations. Temperature controlled preheat, reflow, and cooling stages are involved, with reflow being almost instantaneous.

Solid state The electronic properties of crystalline materials (usually semiconductor in type). The interaction of light, heat, magnetic fields, and electric currents in these crystalline materials are involved in solid state devices. Less power is required to operate solid state devices and a greater variety of effects can be obtained. (2) Technology utilizing solid semiconductors in place of vacuum tubes for amplification, rectification, and switching.

SOS Silicon-on-sapphire transistor device. Silicon is grown on a passive insulating base (sapphire) and then selectively etched away to form a solid state device.

Sputtering A method of depositing a thin film of material onto a substrate. The substrate is placed in a large demountable vacuum chamber having a cathode made of the metal or ceramic to be sputtered. The chamber is then operated so as to bombard the cathode with positive ions. As a result, small particles of the material fall uniformly on the substrate.

Sputtering targets These are usually in the form of simple circular or rectangular plates, comprised of a variety of materials, and bombarded by gas ions that transfer their momentum to particles of the target, ejecting them into the vacuum chamber that houses the operation. These particles are then deposited in a thin film on strategically located substrates.

SSI Small scale integration.

Squeegee Hard, flexible blade with a precision edge which, with applied pressure, forces or pushes ink through the screen in screen printing.

Squeegee pressure Downward force exerted upon the screen and substrate by the squeegee during screen printing.

Squeegee speed Rate of speed at which the squeegee is driven across the screen during screen printing.

Stability The specific ability of electronic circuits or other devices to withstand use and environmental stresses without changing. Also continued operation according to specifications despite adverse conditions.

State This refers to the condition of an input or output of a circuit as to whether it is a logic "1" or a logic "0." The state of a circuit (gate or flip-flop) refers to its output. The flip-flop is said to be in the "1" state when its Q output is "1." A gate is in the "1" state when its output is "1."

Static In burn-in, the quality of a test wherein the device is subject to either forward or reverse bias applied to appropriate terminals; voltages are unvarying throughout test.

Steatite Ceramic material composed mainly of a silicate of magnesium, used as a circuit substrate.

Step To use the step-and-repeat method.

Substrate The physical material upon which an electronic circuit is fabricated. Used primarily for mechanical support but may serve a useful thermal or electrical function. Also, a material on whose surface an adhesive substance is spread for bonding or coating, or any material which provides a supporting surface for other materials.

Subsystem A part or division of a system which in itself has the properties of a system.

Surface diffusion The high temperature injection of atoms into the surface layer of a semiconductor material to form the junctions. Usually a gaseous diffusion process.

Synchronous Operation of a switching network by a clock pulse generator. All circuits in the network switch simultaneously. All actions take place synchronously with the clock.

Synchronous inputs Those terminals on a flip-flop through which data can be entered but only upon command of the clock. These inputs do not have direct control of the output such as those of a gate but only when the clock permits and commands. Called JK inputs or ac set and reset inputs.

System A group of integrated circuits or other components interconnected to perform a single function or number of related functions. If further interconnected into a large system, the individual elements are referred to as subsystems.

Taper testers A taper tester is used to test one aspect of the dimensional integrity of wafers. Taper results when the two faces of the water under test are not parallel.

TCR Temperature coefficient of resistance.

Temperature coefficient of resistance The amount of change in the resistance of a material per degree of temperature rise.

Thermal compression bonding Process of diffusion bonding in which two prepared surfaces are brought into intimate contact, and plastic deformation is induced by the combined effects of pressure and temperature, which in turn results in atom movement causing the development of a crystal lattice bridging the gap between facing surfaces and resulting in bonding.

Thermistor A semiconductor device, the electrical resistance of which varies with the temperature. Its temperature coefficient of resistance is high, nonlinear, and usually negative.

Thick film Conductive, resistive, and/or capacitive passive network deposited on a substrate using a metallic or resistive film which is more than five microns in thickness.

Thick film hybrid integrated circuits The physical realization of a hybrid integrated circuit fabrication on a thick film network.

Thick film resistor, conductor, and dielectric compositions The principle materials for making thick film circuits, available in paste form and consisting of mixtures of metal, oxide, and glass powders.

Thin film Conductive, resistive, and/or capacitive passive network deposited on a substrate using a metallic or resistive film which is less than five microns in thickness.

Thin film deposition, chemical vapor type The CVD technique involves a decomposition and reaction between gases on the surface of a heated substrate such that a solid layer is nucleated and grown. Metals are generally derived from the decomposition of the metal halides. Insulators may be formed by reacting metal halides with oxygen (oxides), ammonia (nitrides), diborane (borides), etc.

Thin film deposition, evaporation type Popular technique for depositing thin film in vacuum, accomplished by heating the source material in a low pressure chamber so that it vaporizes and then condenses onto all cooler surfaces in line-of-sight from the source.

Thin film deposition, sputtering type Evaporation produced by ion bombardment of the source material, known as cathode-sputtering.

Thin film deposition materials, conductors and resistors Metals such as aluminum, gold, chromium, nickel, platinum, tungsten, alloys, and cermets deposited as electrical conductors and resistors on silicon or other substrates.

Thin film deposition materials, inorganic dielectrics Film compounds produced by various vacuum evaporation processes and deposited on substrates to perform electrical functions. Examples include silicon monoxide, ZnS, CaF, SiO₂, Al₂O₃, Si₃N₄, and other chemical compounds.

Thin film deposition materials, organic dielectrics Insulating film compounds produced when organic vapors are heated under conditions in which polymerization and deposition occur. Examples are parylene, butadiene, acrolein, and divinyl benzene.

Thin film deposition materials, semiconductors Polycrystalline films deposited by vacuum or flash evaporation to produce high purity single crystal silicon or other semiconductor substances.

Thin film hybrid integrated circuits The physical realization of a hybrid integrated circuit fabricated on a thin film network.

Thin film integrated circuit The physical realization of a number of electric elements entirely in the form of thin films deposited in a patterned relationship on a structural supporting material.

Toggle To switch between two states as in a flip-flop.

Tooling Vacuum holes, grooves, and locating pins on the tool plate surface dedicated to a certain size substrate in order to position and hold the substrate during the print cycle of screen printing.

TO package Can-type IC chip configuration, an outgrowth of the original TO transistor package. Most common are the TO-5, TO-18, and TO-47. The IC chip is mounted within the package, interconnected to terminals on the can, and then hermetically sealed. TO stands for transistor outline.

Transistance The characteristic of an electric element which controls voltages or current so as to accomplish gain or switching action in a circuit. Examples of the physical realization of transistance occur in transistors, diodes, saturable reactors, limitors, and relays.

Transistor An active semiconductor device having three or more electrodes, and capable of performing almost all the functions of tubes, including rectification and amplification. Germanium and silicon are the main materials used, with impurities introduced to determine the conductivity type (n-type as an excess of free electrons, p-type, a deficiency).

Transistor testers Equipment and instruments which detect or measure leakage current, breakdown voltage, gain, or saturation voltage. Some testers are computer operated.

Trigger A timing pulse used to initiate the transmission of logic signals through the appropriate circuit signal paths.

Trimming Removal of film resistor material in order to increase the resistance to a certain value. Two types of equipment are used for this purpose. The air abrasive jet trimming system (AJT) depends on a precisely controlled stream of abrasive particles to carve away small portions of a thick film resistor. Laser systems are often used for both thick and thin films. With lasers, the material is burned away.

Truth table A chart which tabulates and summarizes all the combinations of possible states of the inputs and outputs of a circuit. It tabulates what will happen at the output for a given input combination.

TTL, T² L (Transistor-Transistor-Logic) A logic system which evolved from DTL wherein the multiple diode cluster is replaced by a multiple-emitter transistor. A circuit which has a multiple emitter input and an active pullup network.

Turn-on time The time required for an output to turn on (sink current, to ground output, to go to 0-V). It is the propagation time of an appropriate input signal to cause the output to go to 0 V.

Turn-off time Same as Turn-on time except the output stops sinking current, goes off and/or goes to a high voltage level (logic "1").

Ultrasonic bond A contact area where two materials are joined by means of ultrasonic energy and pressure.

Ultrasonic wire bonder Equipment unit which fastens fine wire onto substrate by use of ultrasonic energy.

Unit under test (UUT) Any system, set subsystem, assembly, or subassembly undergoing testing.

UV curing Polymerizing, hardening, or cross linking a low molecular weight resinous material in a wet coating or ink, using ultraviolet light as an energy system.

VLSI Very large scale integration.

Vacuum evaporation The creation of thin films by vaporizing the film substance and allowing its deposition onto a substrate through mask openings.

Varistor A two-electrode semiconductor device with a voltage-dependent nonlinear resistance which falls significantly as the voltage is increased.

Via A vertical conductor or conductive path forming the interconnection between multi-layer hybrid circuit layers.

Wafer and die sorters. Equipment which automates the testing and sorting of semiconductor devices from wafer form.

Wafer handling equipment Equipment used for processing silicon wafers using methods which include batch processing in a common carrier, air bearing single wafer processing, and a combination of batch and single wafer processing.

Wafers Slices of semiconductor crystal materials used as substrates for monolithic ICs, diodes, and transistors.

Wet-process benches These are benches or stations used for water processing. Because of the hazardous materials (acids) that are used, they should be designed with personnel safety and contamination control foremost.

Wire bond The fastened union point between a conductor or terminal and the semiconductor die.

Wire, semiconductor lead Fine wire used to connect semiconductor chips to substrate patterns, packages, other chips, etc. Usually made from an aluminum alloy or gold.

Wired "OR" Externally connected separate circuits or functions arranged so that the combination of their outputs results in an "AND" function. The point at which separate circuits are wired together will be an "O" if any one of the separate outputs is an "O." The same as a dot "AND."

Word A group of bits treated as an entity in a computer.

X axis The horizontal or left-to-right direction in a two-dimensional system of coordinates.

X-X Signifies one direction followed in a step-and-repeat method.

"X" motion Registration adjustment left and right of the screen pattern to the substrate, in screen printing.

Y axis The vertical direction, perpendicular to the X axis, in a two-dimensional system of coordinates. Y-Y signifies one direction followed in a step-and-repeat method.

"Y" motion Registration adjustment front to rear of the screen pattern to the substrate, in screen printing.

Zener diode A p-n junction two-terminal, single junction semiconductor device reverse biased into the breakdown region and providing high impedances under less than breakdown voltage but conduction with no impedance above breakdown voltage level.

Zero ("0") See Binary logic.

"Z" motion Vertical adjustment of screen-substrate distance. Used for setting snap-off and leveling in screen printing.

(The glossary includes terms from Insulation/Circuits, May, 1982. Copyright Lake Publishing Corporation, Libertyville, IL 60048. Used with permission.)

CLASSIFICATION OF AMPLIFIERS

The definitions of class A, B, or C operation apply to vacuum tubes as well as to transistor circuits. Bias voltage on the emitter junction of a transistor determines collector current just as grid voltage determines plate current in a vacuum tube.

Class A allows for 360° operation of a sine wave.

Class B operation is with zero bias (cutoff) and allows 180° conduction.

Class C operation is with bias beyond cutoff which allows less than 180° conduction.

Class AB operation allows small-signal class A operation, and large-signal class B operation.

The above classes of operation are defined and illustrated for transistors and vacuum tubes.

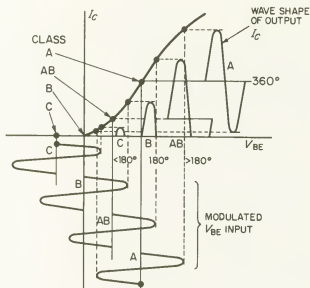
Class	Bias Setting	Input-signal Voltage Swing	Plate or Collector Current Flow	Performance Characteristic
A ₁	Center point of characteristic curve	Confined to linear portion of characteristic curve	Complete cycle	Undistorted output. High gain. Low power conversion efficiency. (25% maximum)
A ₂	Above center point of characteristic curve	Extends into upper (saturation) bend of characteristic curve	Complete cycle	Almost undistorted output. Lower gain but higher efficiency than class A ₁ .
AB ₁	Below center point of characteristic curve	Extends into lower (cutoff) bend of characteristic curve	Cuts off for a small portion of negative half-cycle	In push-pull operation output is practically undistorted. Lower gain but higher efficiency than class A ₂ .
AB ₂	Center point of characteristic curve	Extends into lower (cutoff) and upper (saturation) bends of characteristic curve	Cuts off for small portion of negative half-cycle	Slight harmonic distortion in push-pull operation. Lower gain but higher efficiency than class AB ₁ .
B ₁	Near lower bend of characteristic curve	Extends beyond lower (cutoff) bend of characteristic curve	Cuts off for greater part of negative half-cycle	Little harmonic distortion in push-pull operation. Gain less than class AB ₂ . Maximum efficiency 78.5%.
B ₂	Near lower bend of characteristic curve	Extends into lower (cutoff) and upper (saturation) bend of characteristic curve	Cuts off for greater part of negative half-cycle and small portion of positive half-cycle	Some harmonic distortion in push-pull operation. Lower gain but higher efficiency than class B ₁ .
C	Beyond lower bend of characteristic curve	Extends well beyond lower (cutoff) and upper (saturation) bends of characteristic curve	Cuts off all of negative and part of positive half-cycles	Considerable harmonic distortion. Low gain. High power conversion efficiency (80% maximum).

Subscript 1 denotes that no grid current flows during any part of the cycle.

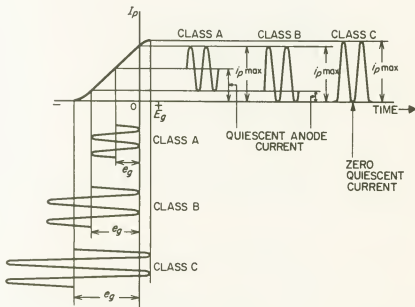
Subscript 2 denotes that grid current flows at least for a portion of the cycle.

In class C amplifiers, grid current always flows, and a subscript is therefore unnecessary.

TRANSISTORS



VACUUM TUBES



RISETIME OF CASCADED AMPLIFIERS

Two cascaded amplifying devices will have an overall risetime given by:

$$T_{rt} = \sqrt{T_{rt_1}^2 + T_{rt_2}^2}$$

where T_{rt_1} , T_{rt_2} , and T_{rt} are the first stage, second stage, and total risetimes respectively.

The above relation is presented in the accompanying graph.

FOR EXAMPLE: A system incorporating two cascaded amplifiers having risetimes of 100 μ sec and 25 μ sec (a ratio of 4:1), would have an overall risetime of 103 μ sec.

NOTE: The Y-axis is the percentage increase in the risetime above the risetime of the slower of two cascaded devices.

Where $A_1, A_2 \dots A_n$ are amplifiers with zero output impedance and infinite input impedance

e_n = square wave of frequency F

Then for TILTS of 10% or less

$$\% \text{ TILT}_1 = \pi \frac{F_1}{F} \times 100 \quad \text{where } F_1 = \frac{1}{2\pi R_1 C_1}$$

TILTS of 10% magnitude or less are additive. Thus

$$\% \text{ TILT}_2 = \pi \left(\frac{F_1}{F} + \frac{F_2}{F} \right) \times 100$$

where

$$F_2 = \frac{1}{2\pi R_2 C_2}$$

and

$$\% \text{ TILT}_n = \pi \left(\frac{F_1}{F} + \frac{F_2}{F} + \dots + \frac{F_n}{F} \right) \times 100$$

By definition

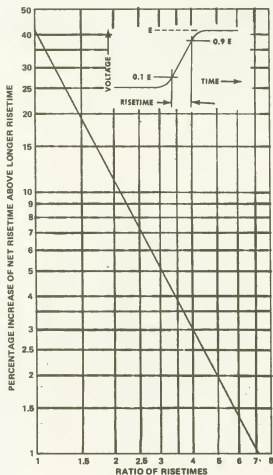
$$\% \text{ TILT} = \frac{V_1 - V_2}{V/2} \times 100 \approx \pi \frac{F_1}{F} \times 100$$

where

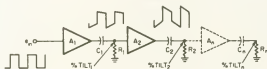
F = Frequency of applied wave e_n

$$F_1 = \frac{1}{2\pi RC} \quad \text{- cutoff of high pass network (3 dB)}$$

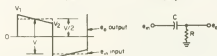
C in farads R in ohms



RC coupled Amplifiers % TH



Square Wave TH Due To RC Coupling

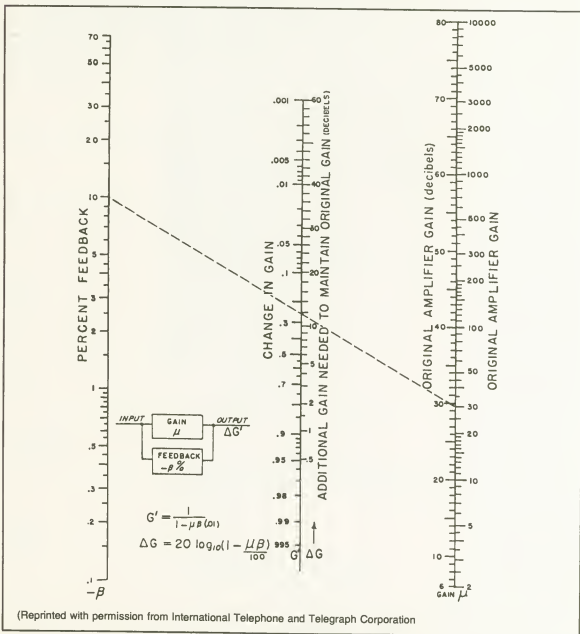


(From *Electronics and Communications*, December, 1968.)

NEGATIVE FEEDBACK NOMOGRAM

In negative-feedback amplifier considerations, β (expressed as a percentage) has a negative value. A line across the β and μ scales will intersect the center scale to indicate resulting change in gain. It also indicates amount (in decibels) by which input must be increased to maintain original output. Original amplification may be expressed as voltage ratio or in decibels by using appropriate scale at right.

FOR EXAMPLE: For a β of 10% and an amplifier μ of 30, the nomogram yields a change in μ of 0.25.



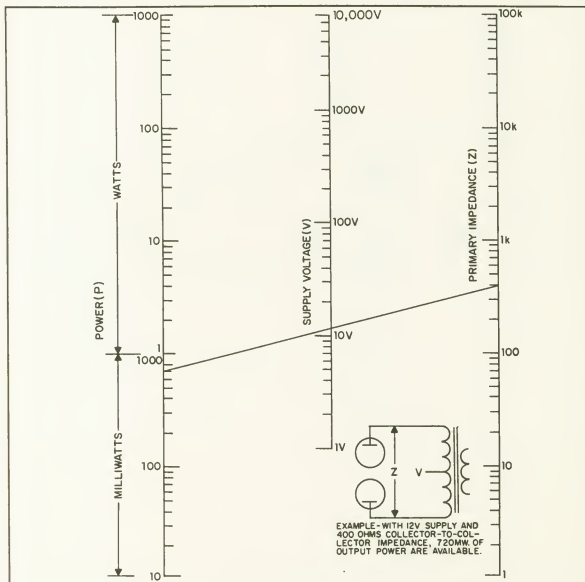
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CLASS B PUSH-PULL AMPLIFIER NOMOGRAM

This nomogram determines the available power from the output of class B vacuum tube or transistor push-pull stage operating under the following conditions: The output is a sine wave, the collector or plate swing is twice the supply voltage, and the available output power is determined by the formula

$$P = \frac{(\sqrt{2} V)^2}{Z}$$

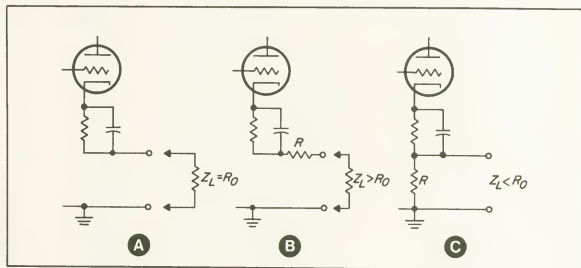
FOR EXAMPLE: A transistor amplifier with a 12-V supply and a collector-to-collector impedance of 400 ohms could produce 720 mW of undistorted output power.

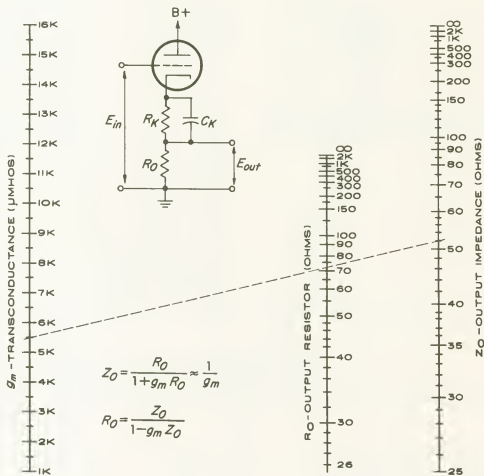


CATHODE FOLLOWER NOMOGRAM

A cathode follower is useful for properly terminating transmission lines and coaxial cables. It provides high Z_{in} and low Z_{out} , good frequency and phase response, ground common to the input and output, reduced input capacitance, power gain and in-phase input and output. To match a transmission line, R_o should equal the impedance of the line (A). If R_o is less, add a series resistor (B), if R_o is greater use a resistor (C) so that $R = R_o Z_o / (R_o - Z_o)$.

FOR EXAMPLE: To drive a 52-ohm line using a tube with a g_m of 5,000 requires an R_o of 70 ohms. To provide proper cathode bias, determine the required cathode resistance from the tube manual or by calculation, and subtract R_o to determine R_K . Assuming that 220 ohms is required for proper bias, the R_K is 150 ohms and R_o is 70 ohms. If fixed bias is used, R_K is not needed.



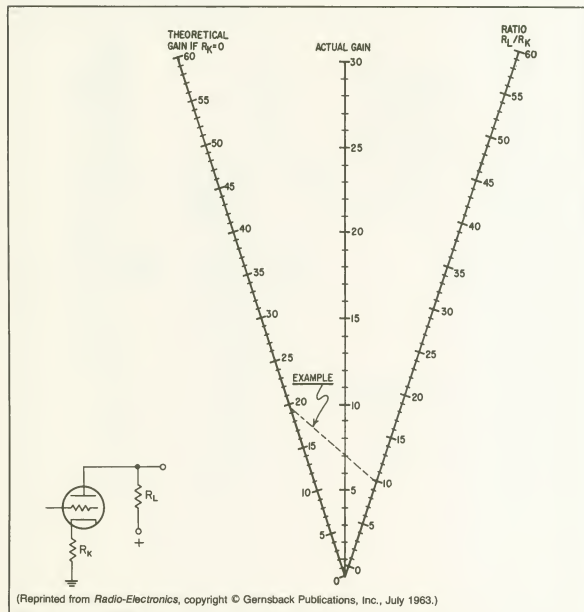


CATHODE FEEDBACK NOMOGRAM

This nomogram shows the reduction in the gain of an amplifier as a result of negative feedback that is introduced if the cathode resistor is not bypassed.

FOR EXAMPLE: What will be the gain of an amplifier that has an initial stage gain of 20, a cathode resistor of 22 K, and a dynamic plate load resistor of 220 K if the cathode bypass capacitor is removed. The ratio of R_L to R_K is 10, thus the resultant "actual" stage gain is 7.

The range of the nomogram can be extended by multiplying all three scales by the same power of 10.



EUROPEAN TUBE NUMBERING SYSTEM

Receiving and Amplifying Tubes

First Letter	Second and Subsequent Letter	Numbers
Type of Filament or Heater	Electrode Structure—Class of Tube	Type of Base
A 4 V ac (parallel)	A Single diode	1 Base indicated by second number
C 200 mA heater	B Dual diode	2 Octal
D 0.5-1.5 V dc	C Triode, small-signal	3 Octal
E 6.3 V ac (parallel)	D Triode, large-signal	4 European rim-lock
G 5 V heater	E Tetrode, small-signal	5 Miscellaneous special bases
H 12.6 V 150 mA heater (parallel)	F Pentode, small-signal	6,7 Subminiature tube
K 2 V dc (parallel)	H Hexode or heptode	8 Nine-pin miniature (noval)
M 2.5 V	K Octode, pentagrid converter	9 Seven-pin miniature
O no filament	L Pentode or tetrode, large-signal	
P 300 mA heater (series)	M Electron-beam indicator	Second and third digits differentiate between tubes that have the same general description but different characteristics. If the first number is a 1, then the second number indicates the type of base.
U 100 mA heater (series)	N Thyatron	
Z code cathode	P Secondary emission tube	
	Q Nonode (9 electrodes)	
	T Miscellaneous	
	X Gas-filled full-wave rectifier	
	Y Vacuum half-wave rectifier	
	Z Vacuum full-wave rectifier	
	Two or more of these letters may be combined. Thus ac indicates a diode and a triode in one envelope.	

FOR EXAMPLE:

Type ECH81 Triode-heptode oscillator converter, with noval socket and 6.3 V heater

Type EL34 Power pentode with octal base and 6.3-V heater

Type GZ34 Full-wave rectifier with octal base and 5-V heater

NOTE: For special tubes (ruggedized, long-life, etc.), the numbers are placed between the letters. For example: E80F, E90CC, E80CF.

Transmitting Tubes

First Letter	Second Letter	Third Letter	Numbers
Tube Type	Filament	Cooling Type	Characteristic
D Rectifier	A Tungsten, directly heated	G Mercury filled	No uniform notation used
M Triode	B Thoriated tungsten, directly heated	L Forced air	
P Pentode	C Oxide coated, directly heated	W Water cooled	
Q Tetrode	E Heater/cathode	X Xenon filled	
T Triode			

FOR EXAMPLE: Type QQE-04-20 Dual tetrode with indirectly heated cathode

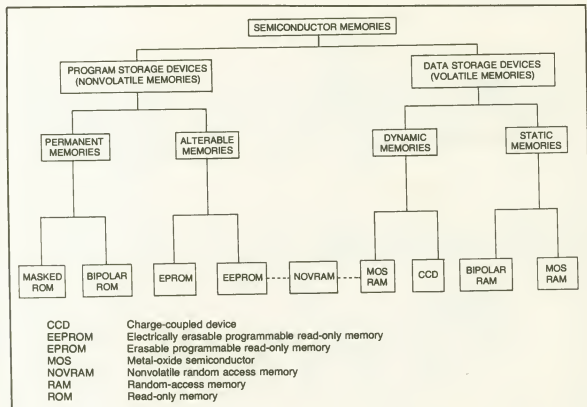
SOLID-STATE SENSING TECHNOLOGIES

This table summarizes the characteristics of solid-state sensors of position, temperature, level, pressure, and speed.

<i>Sensing Technique</i>	<i>Actuation</i>	<i>Actuator</i>	<i>Construction</i>	<i>Advantages</i>	<i>Disadvantages</i>
Hall effect	Proximity	Electromagnet or permanent magnet	Integrated circuit only	Not rate sensitive, fast signal conditioning, simple	Requires magnet actuator, cannot achieve fine resolution
Hall effect vane	Interrupted	Ferrous material	IC, permanent magnet	Integral design, not rate sensitive, low cost, signal conditioning	Magnet attraction mode of actuation, cannot achieve fine resolution
Eddy current resolution	Proximity	Ferrous or	Coil, IC and nonferrous material components	All-metal detector, indiscrete contaminated, high frequency	Cannot achieve fine resolution, discrete unit, not easily
Opt-electronic	Interrupted or reflective	Any opaque material	IC, LED, and components	Defects any opaque material, good resolution	Easily contaminated ambient light sensitive
Piezoelectric	Impact	Any hard material	Crystal	No stand-by power, potentially lowest cost device	Pulse output, requires impact
Piezo-resistance	Pressure or flexing	Gaseous or mechanical	IC	Detection without mechanical linkage	Complex, difficult construction, expensive for accuracy
Variable reluctance (Magnetic) pickup	Proximity	Ferrous	Coil, magnet, IC and discrete components	Fine resolution, integral unit, high speed detection	Cannot sense zero speed, hard signal conditioning, small operate point, complex
Capacitance	Touch or proximity	Any material	IC and sensing capacitor	Detects any low dielectric material	False triggering, moisture and temperature sensitive, complex
Sonic	Audio beam interrupted or reflected	Any material	Transmitter, receiver, IC and discretes	Large sensing gap, detects any material	Triggered by random noise, not precise, non-directional

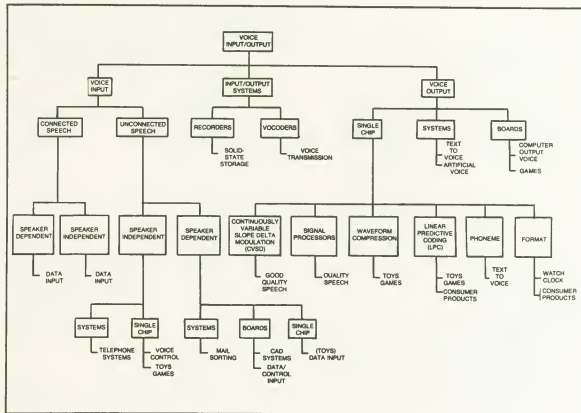
SEMICONDUCTOR MEMORIES

This family tree illustrates the interrelationship of the various types of volatile and nonvolatile semiconductor memories.



VOICE INPUT/OUTPUT FAMILY TREE

Electronic voice input/output capability endows machines with the human qualities of hearing (speech recognition) and speaking (speech output). This family tree highlights some of the current applications of voice input/output equipment.



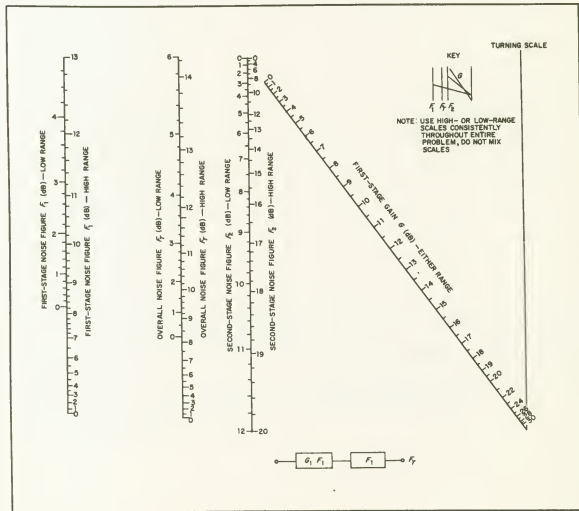
NOISE FIGURE NOMOGRAM FOR TWO CASCADED STAGES

The cascade noise figure of two noise sources is given by the equation

$$F_T = F_1 + \frac{(F_2 - 1)}{G_1}$$

where F_1 , F_2 , and F_T are the first-stage, second-stage, and overall noise figures respectively, and G is the gain of the first stage—all expressed as power ratios. The nomogram has all scales calibrated in decibels. To use the nomogram connect F_2 and G and note the intersect point on the turning scale. That point is then connected to F_T or F_1 depending on which of these figures is given. Two ranges (high and low) are given for all three "F" scales and they must be used together. Only one "G" scale is necessary.

FOR EXAMPLE: A first-stage noise figure of 3 dB, a second-stage noise figure of 7 dB, and a first-stage gain of 8 dB, results in an overall noise figure of 4.2 dB.



Section 5

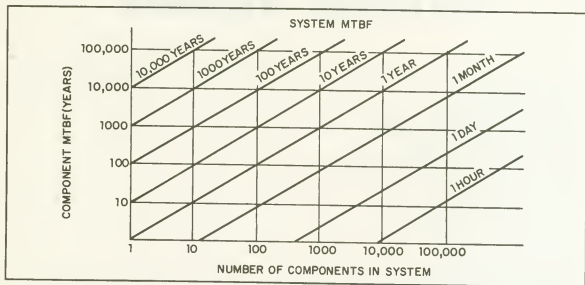
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RELIABILITY CHARTS

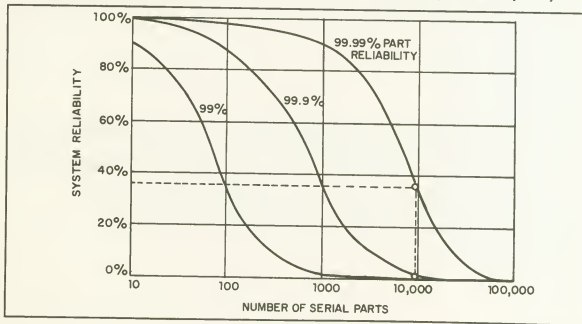
This chart relates system MTBF (Mean-Time-Between-Failures) with the number of components per system and the component MTBF.

FOR EXAMPLE: A system using 10,000 components with a component MTBF of 30 years will have a system MTBF of 1 day.



This chart relates system reliability in percent with the number of serial parts, that is, the critical parts that must function in order for the system to perform its function.

FOR EXAMPLE: 10,000 critical parts with a 99.99% parts reliability provide a system reliability of only 37%.



RELIABILITY NOMOGRAM

Reliability is a dependent function of operating time and failure rate. It is generally given as a percentage or a decimal that states the probability that an equipment will perform its function satisfactorily during a mission. Reliability is based on the formula

$$P_o = e^{-t/T} = e^{-\lambda t}$$

where

$$T = 1/\lambda$$

t = operating time in hours

P_o = probability of success, i.e., reliability

T = mean time between failures

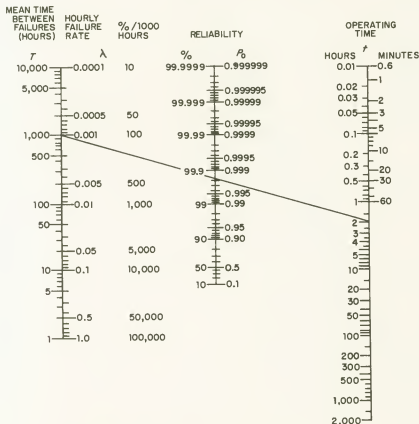
e = base of natural logarithm

λ = failure rate (% per 1,000 hr)

FOR EXAMPLE: A circuit that has a failure rate of 100%/1,000 hr (an hourly failure rate of 0.001 or an MTBF of 1,000) has a reliability of 99.8% when operated for 2 hr. That means that the circuit will not operate properly an average of 2 times out of 1,000 operations, or out of 1,000 circuits an average of 2 will fail in 2 hr.

NOTE: An equipment or circuit with an MTBF of one hour will have a reliability of only 33.788% ($100/e$) when operated for one hour.

NOTE: For more detailed treatment of MTBF see the latest edition of *MIL-Handbook-217*.



(From *Electronics and Communications*, March, 1965.)

RELIABILITY—REDUNDANCY NOMOGRAM

For certain critical applications, such as manned space flights, the required reliability is often greater than what can be achieved with a single system. Under these conditions it is necessary to resort to redundancy where two or more identical systems are paralleled. The required redundancy is based on the following equation:

$$P_N = 1 - (1 - P_o)^N$$

where

P_N = probability of success of N paralleled systems

P_o = probability of success of one system

N = number of paralleled systems

FOR EXAMPLE: A subsystem for a two-week moon exploration flight has a special reliability of 99.99% and a MTBF of 2,000 hr. What is the required redundancy? On reliability nomogram (A) connect 2,000 on the T scale with 336 (2 weeks) on the t scale to determine subsystem reliability to be 0.845. On redundancy nomogram connect 0.845 on the P_o scale with 0.9999 on the P_N scale to determine that a redundancy of five is required.

P_N

0.900
0.920
0.940
0.960
0.970
0.980

0.990
0.992
0.994
0.996
0.997
0.998

0.9990
0.9992
0.9994
0.9996
0.9997
0.9998
0.9999

$$P_N = 1 - (1 - P_0)^N$$

 N

1

.

2

3

4

5

 P_0

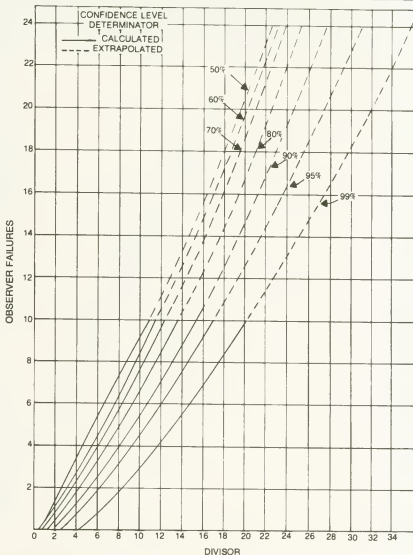
0.99
0.985
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9

0.85
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

CONFIDENCE LEVEL DETERMINATOR

This graph is used to determine the *minimum* MTBF for a given confidence level. To use the chart, determine the actual number of Operating Hours, the Observed Failures, and the required Confidence Level. Read across from "Observed Failures" to "Confidence Level" and then down to obtain the "Divisor." Divide the number of Operating Hours by the "Divisor." The result is the *minimum* MTBF for the stated Confidence Level.

FOR EXAMPLE: During 2,000 hours of operation there were 8 failures. What is MTBF stated with a confidence level of 90%? Reading across 8 to the 90% curve shows the divisor to be 13. Dividing 2,000 by 13 yields approximately 154. Thus, it can be said that the MTBF (minimum) is 154 hours with a confidence of 90%. If, in the above example, a confidence level of 70% had been required, then it could be said that the MTBF was 194 hours with a confidence level of 70%.





















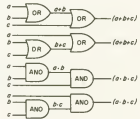


ANGULAR RESOLUTION TABLE













The shaft angle corresponding to an integral binary fraction is required wherever shaft angle encoders are used. This resolution table aids in determining accurately the angle represented by a specific number of counts or conversely, the precise number of counts which equals a given angle.

n	2 ⁿ	1/2 ⁿ , 0001/2 ⁿ (seconds)	Angular Resolution Corresponding to Integral-Binary Fraction	360/2 ⁿ (degrees)	2 ⁿ , 2 ⁿ (radians)	n
0	1	1 794 000	21 600	360.0	0	0
1	2	897 000	10 800	180.0	0.261 8	1
2	4	448 500	5 400	90.0	0.341 5	2
3	8	224 250	2 700	45.0	0.570 7	3
4	16	112 125	1 350	22.5	0.785 4	4
5	32	56 062.5	675	11.25	1.107 1	5
6	64	28 031.25	337.5	5.625	1.570 8	6
7	128	14 015.625	168.75	2.8125	2.221 4	7
8	256	7 007.8125	84.375	1.40625	3.141 6	8
9	512	3 503.90625	42.1875	0.703125	4.441 3	9
10	1 024	1 751.953125	21.09375	0.3515625	6.283 2	10
11	2 048	875.9765625	10.546875	0.17578125	8.726 6	11
12	4 096	437.98828125	5.2734375	0.087890625	12.217 3	12
13	8 192	218.994140625	2.63671875	0.0439453125	17.014 5	13
14	16 384	109.4970703125	1.318359375	0.02197265625	24.427 4	14
15	32 768	54.74853515625	0.6591796875	0.010986328125	34.908 5	15
16	65 536	27.374267578125	0.32958984375	0.0054931640625	50.265 4	16
17	131 072	13.6871337890625	0.164794921875	0.00274658203125	71.673 7	17
18	262 144	6.84356689453125	0.0823974609375	0.001373291015625	101.623 8	18
19	524 288	3.421783447265625	0.04119873046875	0.0006866455078125	142.943 8	19
20	1 048 576	1.7108917236328125	0.020599365234375	0.00034332275390625	205.228 1	20
21	2 097 152	0.85544586181640625	0.0102996826171875	0.000171661376953125	287.424 1	21
22	4 194 304	0.427722930908203125	0.00514984130859375	0.0000858306884765625	400.483 4	22
23	8 388 608	0.21386146545409375	0.002574920654296875	0.00004291534423828125	560.795 2	23
24	16 777 216	0.10693073272734375	0.0012874603271444295	0.00002145767119140625	787.606 3	24
25	33 554 432	0.053465366363671875	0.00064373016357421875	0.0000107288360595703125	1099.959 5	25

THE POSTULATES OF BOOLEAN ALGEBRA

THE LAWS OF COMBINATION	WORDS (English)	MATHEMATICS (Set Theory)	LOGIC	ENGINEERING	GEOMETRICAL DIAGRAMS	
	1. THE LAWS OF TAUTOLOGY Repetition—by addition or multiplication—does not alter the truth value of an element	$a \cup a = a$ $a \cap a = a$	$a \vee a = a$ $a \wedge a = a$	$a + a = a$ $a \cdot a = a$	 	
	2. THE LAWS OF COMMUTATION Disjunction or conjunction is not affected by sequential change—[Disjunction—OR: if either input a or input b, or both inputs a and b, are conducting, then the output (a + b) is conducting. Conjunction—AND: if, and only if, both inputs a and b are conducting, then the output (a · b) is conducting.]	$a \cup b = b \cup a$ $a \cap b = b \cap a$	$a \vee b = b \vee a$ $a \wedge b = b \wedge a$	$a + b = b + a$ $a \cdot b = b \cdot a$	   	
	3. THE LAWS OF ASSOCIATION Disjunction or conjunction is unaffected by grouping	$(a \cup b) \cup c = a \cup (b \cup c)$ $(a \cap b) \cap c = a \cap (b \cap c)$	$(a \vee b) \vee c = a \vee (b \vee c)$ $(a \wedge b) \wedge c = a \wedge (b \wedge c)$	$(a + b) + c = a + (b + c)$ $(a \cdot b) \cdot c = a \cdot (b \cdot c)$	   	
	4. THE LAWS OF DISTRIBUTION An element is added to a product by adding the element to each member of the product. A sum is multiplied by an element by multiplying every member of the sum by the element	$a \cup (b \cap c) = (a \cup b) \cap (a \cup c)$ $a \cap (b \cup c) = (a \cap b) \cup (a \cap c)$	$a \vee (b \wedge c) = (a \vee b) \wedge (a \vee c)$ $a \wedge (b \vee c) = (a \wedge b) \vee (a \wedge c)$	$a + (b \cdot c) = (a + b) \cdot (a + c)$ $a \cdot (b + c) = (a \cdot b) + (a \cdot c)$	   	
	5. THE LAWS OF ABSORPTION The disjunction of a product by one of its members is equivalent to this member. The conjunction of a sum by one of its members is equivalent to this member	$a \cup (a \cap b) = a$ $a \cap (a \cup b) = a$	$a \vee (a \wedge b) = a$ $a \wedge (a \vee b) = a$	$a + (a \cdot b) = a$ $a \cdot (a + b) = a$	 	

CIRCUIT DIAGRAMS	TRUTH TABLES (1 = truth, 0 = falsity)																																																																																																																					
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	WORDS (English)	MATHEMATICS (Set Theory)	LOGIC	ENGINEERING	GEOMETRICAL DIAGRAMS	
THE LAWS OF THE UNIQUE ELEMENTS	1. THE LAWS OF THE UNIVERSE CLASS The sum consisting of an element and the universe class is equivalent to the universe class. The product consisting of an element and the universe class is equivalent to the element	$a \cup I = I$ $a \cap I = a$	$a \vee I = I$ $a \wedge I = a$	$a + I = I$ $a \cdot I = a$	 	
	2. THE LAWS OF THE NULL CLASS The sum consisting of an element and the null class is equivalent to the element. The product consisting of an element and the null class is equivalent to the null class	$a \cup 0 = a$ $a \cap 0 = 0$	$a \vee 0 = a$ $a \wedge 0 = 0$	$a + 0 = a$ $a \cdot 0 = 0$	 	
THE LAWS OF NEGATION (COMPLEMENT)	1. THE LAWS OF COMPLEMENTATION The sum consisting of an element and its complement is equivalent to the universe class. The product consisting of an element and its complement is equivalent to the null class	$a \cup a' = I$ $a \cap a' = 0$	$a \vee \sim a = I$ $a \wedge \sim a = 0$	$a + \bar{a} = I$ $a \cdot \bar{a} = 0$	 	
	2. THE LAW OF CONTRADICTION If an element a is equivalent to the complement of an element b, it is implied that the element b is equivalent to the complement of the element a	$a = b', \bar{b} = a'$	$a = \sim b, \bar{b} = \sim a$	$a = \bar{b}, \bar{b} = \bar{a}$		
	3. THE LAW OF DOUBLE NEGATION The complement of the negation of an element is equivalent to the element	$a = a''$	$a = \sim \sim a$	$a = \bar{\bar{a}}$		
	4. THE LAWS OF EXPANSION The disjunction of a product composed of the elements a and b and a product composed of the elements a and the complement of element b is equivalent to the element a. The conjunction of a sum composed of the elements a and b and a sum composed of the element a and the complement of element b is equivalent to the element a	$(a \cap b) \cup (a \cap b') = a$ $(a \cup b) \cap (a \cup b') = a$	$(a \wedge b) \vee (a \wedge \sim b) = a$ $(a \vee b) \wedge (a \vee \sim b) = a$	$(a \cdot b) + (a \cdot \bar{b}) = a$ $(a + b) \cdot (a + \bar{b}) = a$	 	
THE LAWS OF DUALITY	5. THE LAWS OF DUALITY The complement of a sum composed of the elements a and b is equivalent to the conjunction of the complement of element a and the complement of element b. The complement of a product composed of the elements a and b is equivalent to the disjunction of the complement of element a and the complement of element b	$(a \cup b)' = a' \cap b'$ $(a \cap b)' = a' \cup b'$	$\sim(a \vee b) = \sim a \wedge \sim b$ $\sim(a \wedge b) = \sim a \vee \sim b$	$(a + b)' = \bar{a} \cdot \bar{b}$ $(a \cdot b)' = \bar{a} + \bar{b}$	 	

CIRCUIT DIAGRAMS	TRUTH TABLES (1 = truth, 0 = falsity)																																													
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<p>(a+b) (a-bar+b-bar)</p>	<table><tr><td>a</td><td>b</td><td>$a+b$</td><td>$a \cdot b$</td><td>$\bar{a}+\bar{b}$</td><td>$\bar{a} \cdot \bar{b}$</td><td>$(a+b) \cdot (\bar{a}+\bar{b})$</td></tr><tr><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td></tr><tr><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>0</td></tr></table>	a	b	$a+b$	$a \cdot b$	$\bar{a}+\bar{b}$	$\bar{a} \cdot \bar{b}$	$(a+b) \cdot (\bar{a}+\bar{b})$	1	1	1	1	0	0	0	1	0	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0										
a	b	$a+b$	$a \cdot b$	$\bar{a}+\bar{b}$	$\bar{a} \cdot \bar{b}$	$(a+b) \cdot (\bar{a}+\bar{b})$																																								
1	1	1	1	0	0	0																																								
1	0	1	0	0	1	0																																								
0	1	1	0	0	1	0																																								
0	0	0	0	1	1	0																																								

Boolean Relationships

Idempotent:

$$a + 0 = a \quad a0 = 0 \quad \text{where} \\ a + 1 = 1 \quad a1 = a \quad 0 \equiv \bar{a}$$

$$a + a = a \quad aa = a$$

Commutative: $a + b = b + a$

$$ab = ba$$

Associative: $(a + b) + c = a + (b + c)$

$$(ab)c = a(bc)$$

Distributive: $ab + ac = a(b + c)$

$$a + bc = (a + b)(a + c)$$

Absorption: $a(a + b) \equiv a + ab \equiv a$

DeMorgan Theorem: $\bar{\bar{a}} = a$

$$(\overline{ab}) = \bar{a} + \bar{b} \quad (\overline{a+b}) = \bar{a}\bar{b}$$

$$\overline{a + b} = \bar{a}\bar{b} \quad \overline{\bar{a} + \bar{b}} = a + b$$

Legend:

NOT: The line over a term indicates a false or not true state.

AND: Two terms directly adjacent to each other are called an "AND" function.

OR: Two terms separated by "+" are called an "OR" function.

Examples: $\bar{a}\bar{b}$ reads as "a and not b"







$\bar{a}b$ reads as "Not a and b"

\overline{ab} reads as "Not a and Not b"

$a\bar{b}$ reads as "Not a or Not b"

(See DeMorgan)

Basic Logic

Logic Function	Symbol	Boolean Equation	Truth Table															
AND		$C = AB$	<table><tr><th>A</th><th>B</th><th>C</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	C	0	0	0	0	1	0	1	0	0	1	1	1
A	B	C																
0	0	0																
0	1	0																
1	0	0																
1	1	1																
NAND		$C = \overline{AB} = \bar{A} + \bar{B}$	<table><tr><th>A</th><th>B</th><th>C</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	C	0	0	1	0	1	1	1	0	1	1	1	0
A	B	C																
0	0	1																
0	1	1																
1	0	1																
1	1	0																
OR		$C = A + B$	<table><tr><th>A</th><th>B</th><th>C</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>	A	B	C	0	0	0	0	1	1	1	0	1	1	1	1
A	B	C																
0	0	0																
0	1	1																
1	0	1																
1	1	1																
NOR		$C = \overline{A + B}$	<table><tr><th>A</th><th>B</th><th>C</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	C	0	0	1	0	1	0	1	0	0	1	1	0
A	B	C																
0	0	1																
0	1	0																
1	0	0																
1	1	0																
EXCLUSIVE		$C = A\bar{B} + \bar{A}B$	<table><tr><th>A</th><th>B</th><th>C</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table>	A	B	C	0	0	0	0	1	1	1	0	1	1	1	0
A	B	C																
0	0	0																
0	1	1																
1	0	1																
1	1	0																
INVERT		$C = \bar{A}$	<table><tr><th>A</th><th>C</th></tr><tr><td>1</td><td>0</td></tr><tr><td>0</td><td>1</td></tr></table>	A	C	1	0	0	1									
A	C																	
1	0																	
0	1																	

Clocked Logic Elements

J-K flip-flop

TRUTH TABLE

Inputs at Bit Time t_n Outputs at Bit Time $t_{(n+1)}$

J	K	Q	\bar{Q}
0	0	Q_n	\bar{Q}_n
0	1	0	1
1	0	1	0
1	1	\bar{Q}_n	Q_n

R-S flip-flop

Inputs at Bit Time t_n

Outputs at Bit Time $t_{(n+1)}$

R	S	Q	\bar{Q}
0	0	Q_n	\bar{Q}_n
0	1	1	0
1	0	0	1
1	1	indeterminants	

CONVERSION CHART OF STANDARD METRIC PREFIXES

This chart shows, in their relative positions, symbols, multiples (10^2), and abbreviations for all the international multiples and submultiples as recommended by the International Committee on Weights and Measures (1962) and adapted by the National Bureau of Standards.

This chart provides a fast and easy method of conversion from any metric notation to any other. "Unity" represents the basic unit of measurement such as volts, ohms, watts, amperes, grams, hertz, etc. The number of steps up or down between the two prefixes which are being compared is equal to the direction *and* the number of places in which the decimal point has to be moved to convert from one to the other.

FOR EXAMPLE: To convert 0.0032 milliampere to nanoampere—move six places down. Answer: 3,200 nA.

To convert 43,280 kilohertz to megahertz—move three places up. Answer: 43.28 MHz.

To convert 10.74 microns to millimeters—move three places up. Answer: 0.01074 mm.

DEFINITION	MULTIPLIER	SYMBOL	NAME	CLASSIFICATION
	10^{18}	E	exa	MULTIPLES
	10^{15}	P	peta	
million millions (British billion) or trillion	10^{12}	T	tera	
thousand millions (American billion)	10^9	G	giga	
millions	10^6	M	mega	UNITY
thousands	10^3	k	kilo	
hundreds	10^2	h	hecto	
tens	10^1	d	deca	
tenths	10^{-1}	d	deci	SUBMULTIPLES
hundredths	10^{-2}	c	centi	
thousandths	10^{-3}	m	milli	
millionths	10^{-6}	μ	micro	
thousandths of a million (or millimicro) or billionth nano	10^{-9}	n	nano	
millionth of a million (or micromicro) or trillionth	10^{-12}	p	pico	
thousandths of a millionth (or millimicromicro) or quadrillionth	10^{-15}	f	femto	
millionths of a millionth of a millionth (or quintillionth)	10^{-18}	a	atto	

HARMONIC REJECTION NOMOGRAM

This scale relates the magnitude of harmonic distortion, expressed as a rejection ratio in decibels, to percentage of distortion.

FOR EXAMPLE: (1.) A design specifies that a given audio sine-wave oscillator should have its closest harmonic at least 28 dB below the fundamental. The chart indicates that the closest harmonic must be less than 3.9% of the magnitude of the fundamental.

(2.) Find the harmonic content of a signal made up of the following:

Fundamental frequency	100 V rms
Second harmonic	5 V rms
Third harmonic	2 V rms

Adding harmonics vectorially gives

$$\sqrt{5^2 + 2^2} = 5.39$$

$$\% \text{ distortion} = \frac{\text{harmonic voltage}}{\text{fundamental voltage}} \times 100 = \frac{5.39}{100} \times 100$$

Thus the distortion is 5.30%, which means that the harmonic content of the signal is 25.2 dB below the fundamental.



POWERS OF TWO

2^n	n	2^{-n}	n	2^n
2	1	0.5	73	94447 32965 73929 04273 92
4	2	0.25	74	18889 46593 14785 80854 784
8	3	0.125	75	37778 93186 29571 61709 568
16	4	0.0625	76	75557 86372 59143 23419 136
32	5	0.03125	77	15111 57274 51828 64083 872
64	6	0.015625	78	30223 14549 03857 29367 6544
128	7	0.0078125	79	60446 29098 07314 58735 3068
256	8	0.00390625	80	12089 25819 61462 91747 06176
512	9	0.001953125	81	24178 51639 22295 83494 12352
1024	10	0.0009765625	82	48357 03218 45851 86968 24704
2048	11	0.00048828125	83	96714 06558 91703 33978 49408
4096	12	0.000244140625	84	19342 81311 38340 86795 29881 8
8192	13	0.0001220703125	85	38685 82822 76681 33590 59763 2
16384	14	0.00006103515625	86	77371 25245 53382 87181 19508 4
32768	15	0.000030517578125	87	15474 25049 10072 53436 23905 28
65536	16	0.0000152587890625	88	30948 50096 21345 08872 47810 56
131072	17	0.00000762939453125	89	61897 00196 42690 13744 95621 12
262144	18	0.000003814697265625	90	12379 40039 28536 02748 99124 224
524288	19	0.0000019073486328125	91	24758 80078 57076 05407 06248 448
1048576	20	0.00000095367431640625	92	49517 60157 14152 10996 96496 896
2097152	21	0.000000476837158203125	93	99035 20314 28304 21991 92903 792
4194304	22	0.0000002384185791015625	94	19807 04062 85600 84398 38596 7584
8388608	23	0.00000011920928955078125	95	39614 08125 71321 68796 77197 5168
16777216	24	0.000000059604644773190625	96	79228 18251 42643 37963 54395 0336
33554432	25	0.0000000298023223876953125	97	15845 63250 28528 87516 70819 00672
67108864	26	0.00000001490116119384765625	98	31691 25000 57057 35037 41758 01344
134217728	27	0.00000000745058059632828125	99	63362 50001 14114 70074 83518 02688
268435456	28	0.000000003725290964619140625	100	12678 53082 28220 84014 96703 20537 8
536870912	29	0.00000000186264614923095703125		
1073741824	30	0.000000000931322574615478515625		
2147483648	31	0.000000000465661287307392578125		
4294967296	32	0.0000000002328306438536962890625		
8589934592	33	0.00000000011641532182639481453125		
17179869184	34	0.0000000000582076609134674072265625		
34359738368	35	0.00000000002910383045673370361328125		
68719476736	36	0.00000000001455191228366851860640625		
137438953472	37	0.000000000007275957614834259033203125		
274877906944	38	0.0000000000036379780709171295166015625		
549755813888	39	0.000000000001818989403545856475830078125		
1099511627776	40	0.0000000000009094947017729282379150390625		
2199023255552	41	0.00000000000045474725088646411895751953125		
4398046511104	42	0.00000000000022737975443232059478759765625		
8796093022208	43	0.000000000000113686837216160297397398828125		
17592186044416	44	0.000000000000056843186080801486968994140625		
35184372888352	45	0.00000000000002842170943040400743484970703125		
70368744776704	46	0.0000000000000142108547151902003717422482515625		
140737488353280	47	0.00000000000000710542735760100185871124267578125		
281474976710560	48	0.000000000000003552716788005009293552337890625		
562949953421120	49	0.000000000000001776356839400290464677810689453125		
1125899906842240	50	0.0000000000000008818419700125232338905334425625		
2251799813684480	51	0.000000000000000440992098050626169452667236128125		
4503599627370976	52	0.000000000000000220446049250313080847263361840825		
9007199254740992	53	0.00000000000000011022302462155654042363166808203125		
18014398509481984	54	0.000000000000000056111231257827021181583404541015625		
36028797018963968	55	0.00000000000000002775557561528891310907917022075078125		
72057994037927936	56	0.0000000000000000137778780781456755295395851352590625		
14411588075858752	57	0.00000000000000000688939039072283776476979255674263953125		
28822375815171744	58	0.0000000000000000034469446951953514188823689627838154765625		
576446752303421888	59	0.00000000000000000173472347857680799441924481391906738820125		
115292150460684976	60	0.0000000000000000008673617379884035472059622406959533690140625		
230584309231693952	61	0.000000000000000000433680668994201773602981120347976884703125		
461168601842378904	62	0.0000000000000000002184604349710088801490560347598834228515625		
922337203685477808	63	0.00000000000000000010923057261578034052714546800505437400749689941714278125		
18446744079709581616	64	0.00000000000000000005461210862472522170037264043497085719928625		
3689348814741910232	65	0.0000000000000000000271050543121376105801863202174854785643125		
737869762382064664	66	0.0000000000000000000135525271560680529318010107471392822285625		
14757395289867412928	67	0.00000000000000000000678263578034052714546800505437400749689941714278125		
295147905179352825856	68	0.000000000000000000003388131789012013562529300271185678480556640625		
590295810358705517312	69	0.000000000000000000001694065894508607813884500135928392102783203125		
1180591620714033024	70	0.0000000000000000000008470329472510033906832616419620913916015625		
236118324143482266064	71	0.0000000000000000000004235164736271502169533616125033982010295490078125		
472236648286964521896	72	0.0000000000000000000002117582381375808476708062512991904905128479003906848		

SQUARES, CUBES, AND ROOTS

n	n^2	\sqrt{n}	$\sqrt{10n}$	n^3	n	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$
1	1	1.000000	3.162278	1	1	1.000000	2.154435	4.641589
2	4	1.414214	4.472136	8	2	1.259921	2.714418	5.848035
3	9	1.732051	5.477226	27	3	1.442250	3.107233	6.694330
4	16	2.000000	6.324555	64	4	1.587401	3.419952	7.368063
5	25	2.236068	7.071068	125	5	1.709976	3.684031	7.937005
6	36	2.449490	7.745967	216	6	1.817121	3.914868	8.434327
7	49	2.645751	8.366600	343	7	1.912931	4.121285	8.879040
8	64	2.828427	8.944272	512	8	2.000000	4.308869	9.283178
9	81	3.000000	9.486833	729	9	2.080084	4.481405	9.654894
10	100	3.162278	10.000000	1,000	10	2.154435	4.641589	10.000000
11	121	3.316625	10.488090	1,331	11	2.223960	4.791420	10.322800
12	144	3.464102	10.954450	1,728	12	2.289428	4.932424	10.626590
13	169	3.605551	11.401750	2,197	13	2.351335	5.065797	10.913930
14	196	3.741657	11.832160	2,744	14	2.410142	5.192494	11.186890
15	225	3.872983	12.247450	3,375	15	2.466212	5.313293	11.447114
16	256	4.000000	12.649110	4,096	16	2.519842	5.428835	11.696070
17	289	4.123106	13.036400	4,913	17	2.571282	5.539658	11.934830
18	324	4.242641	13.416410	5,832	18	2.620741	5.646216	12.164400
19	361	4.358899	13.784050	6,859	19	2.668402	5.748897	12.385620
20	400	4.472136	14.142140	8,000	20	2.714418	5.848035	12.599210
21	441	4.582576	14.491380	9,261	21	2.758924	5.943922	12.805790
22	484	4.690416	14.832400	10,648	22	2.802039	6.036811	13.005910
23	529	4.795832	15.185750	12,167	23	2.843867	6.126926	13.200060
24	576	4.898979	15.491930	13,824	24	2.884499	6.214465	13.388660
25	625	5.000000	15.811390	15,625	25	2.924018	6.299605	13.572090
26	676	5.099020	16.124520	17,576	26	2.962496	6.382504	13.750690
27	729	5.196152	16.431660	19,683	27	3.000000	6.463304	13.924770
28	784	5.291503	16.733200	21,952	28	3.036589	6.542133	14.094600
29	841	5.385165	17.029390	24,389	29	3.072317	6.619106	14.260430
30	900	5.477226	17.320510	27,000	30	3.107233	6.694330	14.422250
31	961	5.567764	17.606820	29,791	31	3.141381	6.767899	14.581000
32	1,024	5.656854	17.888540	32,768	32	3.174902	6.839904	14.736130
33	1,089	5.744563	18.165900	35,937	33	3.207534	6.910423	14.888060
34	1,156	5.830952	18.439090	39,304	34	3.239612	6.979532	15.036950
35	1,225	5.916080	18.708290	42,875	35	3.271066	7.047299	15.182940
36	1,296	6.000000	18.973670	46,656	36	3.301927	7.113787	15.326190
37	1,369	6.082763	19.235380	50,653	37	3.332222	7.179054	15.466800
38	1,444	6.164414	19.493590	54,872	38	3.361975	7.243156	15.604910
39	1,521	6.244998	19.748420	59,319	39	3.391211	7.306144	15.740610
40	1,600	6.324555	20.000000	64,000	40	3.419952	7.368063	15.874010
41	1,681	6.403124	20.248460	68,921	41	3.448217	7.428959	16.005210
42	1,764	6.480741	20.493900	74,088	42	3.476027	7.488872	16.134290
43	1,849	6.557439	20.736440	79,507	43	3.503398	7.547842	16.261330
44	1,936	6.633250	20.976180	85,184	44	3.530348	7.605905	16.386430
45	2,025	6.708204	21.213200	91,125	45	3.556893	7.663094	16.509640
46	2,116	6.782330	21.447610	97,336	46	3.583048	7.719443	16.631030
47	2,209	6.855655	21.679540	103,823	47	3.608826	7.774980	16.750690
48	2,304	6.928203	21.908900	110,592	48	3.634241	7.829735	16.868660
49	2,401	7.000000	22.135940	117,649	49	3.659306	7.883735	16.984990
50	2,500	7.071068	22.360680	125,000	50	3.684031	7.937005	17.099770

n	n^2	\sqrt{n}	$\sqrt{10n}$	n^3	n	\sqrt{n}	$\sqrt{10n}$	$\sqrt{100n}$
50	2,500	7.071068	22.36068	125,000	50	3.684031	7.937005	17.09976
51	2,601	7.141428	22.58318	132,651	51	3.708430	7.989570	17.21301
52	2,704	7.211103	22.80351	140,608	52	3.732511	8.041452	17.32478
53	2,809	7.280110	23.02173	148,877	53	3.756286	8.092672	17.43513
54	2,916	7.348469	23.23790	157,464	54	3.779763	8.143253	17.54411
55	3,025	7.416198	23.45208	166,375	55	3.802952	8.193213	17.65174
56	3,136	7.483315	23.66432	175,616	56	3.825862	8.242571	17.75808
57	3,249	7.549834	23.87467	185,193	57	3.848501	8.291344	17.86316
58	3,364	7.615773	24.08319	195,112	58	3.870877	8.339551	17.96702
59	3,481	7.681146	24.28992	205,379	59	3.892996	8.387207	18.06969
60	3,600	7.745967	24.49490	216,000	60	3.914868	8.434327	18.17121
61	3,721	7.810250	24.69818	226,981	61	3.936497	8.480926	18.27160
62	3,844	7.874008	24.89980	238,328	62	3.957892	8.527019	18.37091
63	3,969	7.937254	25.09980	250,047	63	3.979057	8.572619	18.46915
64	4,096	8.000000	25.29822	262,144	64	4.000000	8.617739	18.56636
65	4,225	8.062258	25.49510	274,625	65	4.020726	8.662391	18.66256
66	4,356	8.124038	25.69047	287,496	66	4.041240	8.706588	18.75777
67	4,489	8.185353	25.88436	300,763	67	4.061548	8.750340	18.85204
68	4,624	8.246211	26.07681	314,432	68	4.081655	8.793659	18.94536
69	4,761	8.306624	26.26785	328,509	69	4.101566	8.836556	19.03778
70	4,900	8.366600	26.45751	343,000	70	4.121285	8.879040	19.12931
71	5,041	8.426150	26.64583	357,911	71	4.140818	8.921121	19.21997
72	5,184	8.485281	26.83282	373,248	72	4.160168	8.962809	19.30979
73	5,329	8.544004	27.01851	389,017	73	4.179339	9.004113	19.39877
74	5,476	8.602325	27.20294	405,224	74	4.198336	9.045042	19.48695
75	5,625	8.660254	27.38613	421,875	75	4.217163	9.085603	19.57434
76	5,776	8.717798	27.56810	438,976	76	4.235824	9.125805	19.66095
77	5,929	8.774964	27.74887	456,533	77	4.254321	9.165656	19.74681
78	6,084	8.831761	27.92848	474,552	78	4.272659	9.205164	19.83192
79	6,241	8.888194	28.10694	493,039	79	4.290840	9.244335	19.91632
80	6,400	8.944272	28.28427	512,000	80	4.308869	9.283178	20.00000
81	6,561	9.000000	28.46050	531,441	81	4.326749	9.321698	20.08299
82	6,724	9.055385	28.63564	551,368	82	4.344481	9.359902	20.16530
83	6,889	9.110434	28.80972	571,787	83	4.362071	9.397796	20.24694
84	7,056	9.165151	28.98275	592,704	84	4.379519	9.435388	20.32793
85	7,225	9.219544	29.15476	614,125	85	4.396830	9.472682	20.40828
86	7,396	9.273618	29.32576	636,056	86	4.414005	9.509685	20.48800
87	7,569	9.327379	29.49576	658,503	87	4.431048	9.546403	20.56710
88	7,744	9.380832	29.66479	681,472	88	4.447960	9.582840	20.64560
89	7,921	9.433981	29.83287	704,969	89	4.464745	9.619002	20.72351
90	8,100	9.486833	30.00000	729,000	90	4.481405	9.654894	20.80084
91	8,281	9.539392	30.16621	753,571	91	4.497941	9.690521	20.87759
92	8,464	9.591663	30.33150	778,688	92	4.514357	9.725888	20.95379
93	8,649	9.643651	30.49590	804,357	93	4.530655	9.761000	21.02944
94	8,836	9.695360	30.65942	830,584	94	4.546836	9.795861	21.10454
95	9,025	9.746794	30.82207	857,375	95	4.562903	9.830476	21.17912
96	9,216	9.797959	30.98387	884,736	96	4.578857	9.864848	21.25317
97	9,409	9.848858	31.14482	912,673	97	4.594701	9.898983	21.32671
98	9,604	9.899495	31.30495	941,192	98	4.610436	9.932884	21.39975
99	9,801	9.949874	31.46427	970,299	99	4.626065	9.966555	21.47229
100	10,000	10.00000	31.62278	1,000,000	100	4.641589	10.00000	21.54435

POWERS OF NUMBERS n^4 to n^8

n	n^2	n^3	n^4	n^5	n^6	n^7	n^8
1	1	1	1	1	1	1	1
2	4	8	16	32	64	128	256
3	9	27	81	243	729	2187	6561
4	16	64	256	1024	4096	16384	65536
5	25	125	625	3125	15625	78125	390625
6	36	216	1296	7776	46656	279936	1679616
7	49	343	2401	16807	117649	823543	5764801
8	64	512	4096	32768	262144	2097152	16777216
9	81	729	6561	59049	531441	4782969	43046721
10	100	1000	10000	100000	1000000	10000000	100000000
11	121	1331	14641	161051	1771561	19487171	21436881
12	144	1728	20736	248832	2985984	35831808	42996176
13	169	2197	28561	371293	4826809	62748517	81573073
14	196	2744	38416	537824	7529536	105413504	14575891
15	225	3375	50625	759375	11390625	170859375	256269600
16	256	4096	65536	1048576	16777216	268435456	429496736
17	289	4913	83521	1419857	24137569	410336773	69757474
18	324	5832	104976	1696956	30412224	541222032	910199600
19	361	6859	130321	2476099	47045881	893871739	169835630
20	400	8000	160000	3200000	64000000	128000000	256000000
21	441	9261	194481	4084131	85766121	1801069	3782296
22	484	10648	234256	5153632	113379904	2494358	5487587
23	529	12167	279841	6436343	148035889	3404825	7831099
24	576	13824	331776	7962624	191102976	4586471	11007531
25	625	15625	390625	9765625	244140625	6103816	15256789
26	676	17696	456976	11651376	308515776	8031810	20882706
27	729	19683	531441	14348807	387420489	10460353	28242954
28	784	21952	614656	17210368	461690304	13492929	37780200
29	841	24389	707821	20511149	594823321	17249676	50024641
30	900	27000	810000	24300000	72900000	21600000	64800000
31	961	29781	923521	28629151	8875037	2.751261	6.526910
32	1024	32768	1048576	33554432	10.737418	3.435974	10.995116
33	1089	35937	1185921	39135393	12.914680	4.261844	14.064088
34	1156	39304	1363536	4534924	15.448044	5.292335	17.857939
35	1225	42875	1560625	52521875	18.382056	6.433830	22.518754
36	1296	46656	1796916	60466176	21.767823	7.836416	28.211099
37	1369	50653	1974161	67343957	25.857264	9.493188	35.124795
38	1444	54868	2205136	76234196	30.109364	11.441558	43.477921
39	1521	59319	2313441	90224199	35.187438	13.723101	53.520093
40	1600	64000	2560000	102400000	40960000	16384000	65536000
41	1681	68881	2825761	115856201	4.750104	19.475427	7.984925
42	1764	73968	3111696	130691232	5.489632	23.059333	9.580652
43	1849	79507	3418801	147008443	6.321363	27.181891	11.688200
44	1936	85504	3748096	164916224	7.256314	31.927781	14.048224
45	2025	91689	4100625	184528125	8.303766	37.366945	16.815125
46	2116	97736	4477456	205962976	9.474297	43.581766	20.047612
47	2209	104007	4878661	229345007	10.779215	50.862312	23.811297
48	2304	110632	5308416	254803968	12.230590	58.706634	28.179280
49	2401	117649	5764801	282475249	13.641287	67.622307	33.232931
50	2500	125000	6250000	312500000	15.625000	78.125000	39.062500
51	2601	132651	6751681	345029251	17.596288	90.874107	45.767894
52	2704	140608	7298560	380204032	19.770610	105.280713	53.459979
53	2809	149297	7900481	418195493	22.164361	121.747111	62.525963
54	2916	158496	8503056	459165024	24.794911	139.98252	7230196
55	3025	168125	9150625	503284375	27.680641	160.720452	8373398
56	3136	178256	9834496	550731776	30.840979	172.70948	9.671731
57	3249	188961	10556001	601920257	34.296447	19.548975	11.142916
58	3364	199952	11318496	656356768	38.068693	22.079842	12.808308
59	3481	211681	12117361	714922499	42.180534	24.889515	14.683044
60	3600	225000	12960000	7776000	4.665600	27.993600	16.796160
61	3721	238321	13845841	8445963	5.125037	31.427428	19.170731
62	3844	251664	14776336	9161326	5.680024	35.216146	21.834011
63	3969	265185	15752961	9924385	6.252350	39.398906	24.815578
64	4096	278976	16777216	10737416	6.841948	43.980465	28.147496
65	4225	293063	17850625	11602096	7.571889	49.022279	31.864481
66	4356	307416	18974736	12523326	8.265395	54.551607	36.004061
67	4489	322011	20138176	13501251	9.035336	60.607116	40.606786
68	4624	336896	21387176	14539636	9.886746	67.229886	45.713284
69	4761	352081	22667121	15640313	10.791616	74.463533	51.379837
70	4900	367600	24010000	16807000	11.764000	82.35430	5.764801
71	5041	383441	25411681	18042294	12.810028	9.066120	6.457536
72	5184	399616	26873856	19437147	13.931407	10.030613	7.222041
73	5329	416161	28396241	20730716	15.133423	11.047399	8.064601
74	5476	433056	29986672	22190086	16.405449	12.151280	8.991947
75	5625	450225	31646025	23730469	17.797852	13.345389	10.011292
76	5776	467776	33382176	25355254	19.266993	14.645195	11.130346
77	5929	485681	35153041	27067842	20.842238	16.048523	12.357363
78	6084	503952	36975056	28871744	22.519990	17.565569	13.701144
79	6241	522581	38950000	30.770564	24.308746	19.203909	15.171088
80	6400	540000	40960000	32.768000	26.214400	20.971520	16.777216
81	6561	558321	43046736	34.867644	28.242954	22.876792	18.530022
82	6724	576864	45212176	37.073984	30.400667	24.928547	20.441409
83	6889	595681	47458321	39.390406	32.694037	27.136051	22.522922
84	7056	614816	49877136	41.821194	35.129803	29.500335	24.781589
85	7225	634375	52200625	44.370531	37.714952	32.057709	27.249053
86	7396	654216	54700816	46.940732	40.458754	34.792782	29.811793
87	7569	674449	57289781	49.642092	43.362850	37.725479	32.621167
88	7744	695056	59969536	52.373192	46.440409	40.867580	35.963542
89	7921	716081	62742241	55.840594	49.899129	44.231335	39.365888
90	8100	737600	65610000	5.533600	10.534410	4.782699	4.304672
91	8281	759481	68617961	6.240321	5.678993	5.167610	4.702525
92	8464	781696	71763296	6.958015	6.065506	5.578466	5.132189
93	8649	805201	74950501	7.695884	6.489894	6.017009	5.595818
94	8836	829936	78074896	8.339040	6.968698	6.484776	6.095689
95	9025	855925	81450625	7.737809	7.350919	6.983373	6.632404
96	9216	883136	84934656	8.153727	7.827578	7.514475	7.213896
97	9409	911641	88529281	8.587340	8.329720	8.079828	7.837434
98	9604	931384	92298616	9.039896	8.854924	8.681255	8.507630
99	9801	952401	96059601	9.509900	9.414801	9.320653	9.227447
100	10000	1000000	100000000	10.000000	10.000000	10.000000	10.000000

MATHEMATICAL SIGNS AND SYMBOLS

.	Radix (base) point
*	Logic multiplication symbol
∞	Infinity
+	Plus, positive, logic OR function
-	Minus, negative
\pm	Plus or minus, positive or negative
\mp	Minus or plus, negative or positive
\times	Times, logic AND function
\div	Divided by
/	Divided by (expressive of a ratio)
=	Equal to
\equiv	Identical to, is defined by
\approx	Approximately equal to, congruent to
\simeq	Approximately equal to
\neq	Not equal to
\sim	Similar to
$<$	Less than
\nless	Not less than
\ll	Much less than
$>$	Greater than
\ngtr	Not greater than
\gg	Much greater than
\leq	Equal to or less than
\geq	Equal to or greater than
\propto	Proportional to, varies directly as
\rightarrow	Approaches
:	Is to, proportional to
••	Therefore
#	Number
%	Percent
@	At the rate of; at cost of
ϵ or e	The natural number = 2.71828
π	Pi \approx 3.14159... ~
()	Parentheses. Used to enclose a common group of terms.
[]	Brackets. Used to enclose a common group of terms which includes one or more groups in parentheses.
{ }	Braces. Used to enclose a common group of terms which includes one or more groups in brackets.
\angle	Angle
$^{\circ}$	Degrees (arc or temperature)
'	Minutes, prime
"	Seconds, double prime
||	Parallel to
\perp	Perpendicular to
...	And beyond, ellipsis

$x + y$	x added to y , x OR y
$x - y$	y subtracted from x
$x \cdot y$, $x \times y$, or xy	x multiplied by y , x AND y
$x \div y$	x divided by y
x/y or $\frac{x}{y}$	x divided by y
$1/x$	Reciprocal of x
x^n	x raised to the indicated power of n
$\sqrt[n]{x}$	Indicated root ($\sqrt[n]{}$) of x
$x : y$	x is to y
$|x|$	Absolute value of x , magnitude of x
\vec{X} , \hat{X} , or \mathbf{X}	Vector X
\bar{x}	Average value of x
$f(x)$ or $F(x)$	Function of x
i	$\sqrt{-1}$
j	Operator, equal to $\sqrt{-1}$
Δx	Increment of x
dx	Differential of x
∂x	Partial differential of x
$\frac{\Delta x}{\Delta y}$	Change in x with respect to y
$\frac{dx}{dy}$	Derivative of x with respect to y
$\frac{d}{dy}(x)$	Derivative of x with respect to y
$D_y x$	Derivative of x with respect to y
$\frac{\partial x}{\partial y}$	Partial derivative of x with respect to y
Σ	Summation
Σ_a^b	Summation between limits (from a to b)
Π	Product
\prod_a^b	Product between limits (from a to b)
\int	Integral
\int_a^b	Integral between limits (from a to b)
$\int x dy$	Integral of x with respect to y
$|_a$	Evaluated at a
$|_a^b$	Evaluated between limits (from a to b)

FACTORIALS

Numerical

n	$\frac{1}{n!}$					$n!$	n
1	1.					1	1
2	0.5					2	2
3	.16666	66666	66666	66666	66667	6	3
4	.04166	66666	66666	66666	66667	24	4
5	.00833	33333	33333	33333	33333	120	5
6	0.00138	88888	88888	88888	88889	720	6
7	.00019	84126	98412	69841	26984	5040	7
8	.00002	48015	87301	58730	15873	40320	8
9	.00000	27557	31922	39858	90653	3 62880	9
10	.00000	02755	73192	23985	89065	36 28800	10
11	0.00000	00250	52108	38544	17188	399 16800	11
12	.00000	00020	87675	69878	68099	4790 01600	12
13	.00000	00001	60590	43836	82161	62270 20800	13
14	.00000	00000	11470	74559	77297	8 71782 91200	14
15	.00000	00000	00764	71637	31820	130 76743 68000	15
16	0.00000	00000	00047	79477	33239	2092 27898 88000	16
17	.00000	00000	00002	81145	72543	35568 74280 96000	17
18	.00000	00000	00000	15619	20697	6 40237 37057 28000	18
19	.00000	00000	00000	00822	06352	121 64510 04088 32000	19
20	.00000	00000	00000	00041	10318	2432 90200 81766 40000	20

$$n! = 1 \times 2 \times 3 \times 4 \times 5 \dots n$$

FOR EXAMPLE: For $n = 7$, $n! = 5040$.

$$1/n! = 0.001984126984126984126984,$$

$$\log(n!) = 3.702431.$$

Logarithmic

Logarithms of the products $1 \times 2 \times 3 \dots n$, n from 1 to 100.

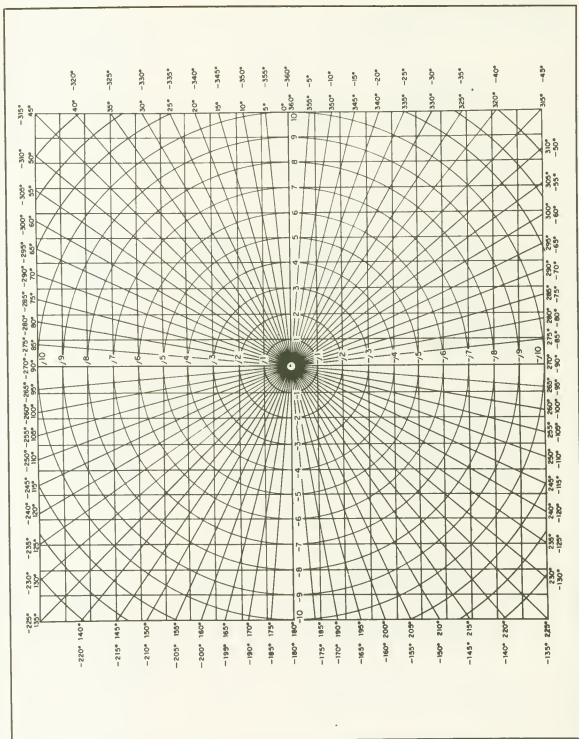
n	$\log(n!)$	n	$\log(n!)$	n	$\log(n!)$	n	$\log(n!)$
1	0.000000	26	26.605619	51	66.190645	76	111.275425
2	0.301030	27	28.036983	52	67.906648	77	113.161916
3	0.778151	28	29.484141	53	69.630924	78	115.054011
4	1.380211	29	30.946539	54	71.363318	79	116.951638
5	2.079181	30	32.423660	55	73.103681	80	118.854728
6	2.857332	31	33.915022	56	74.851869	81	120.763213
7	3.702431	32	35.420172	57	76.607744	82	122.677027
8	4.605521	33	36.938686	58	78.371172	83	124.596105
9	5.559763	34	38.470165	59	80.142024	84	126.520384
10	6.559763	35	40.014233	60	81.920175	85	128.449803
11	7.601156	36	41.570535	61	83.705505	86	130.384301
12	8.680337	37	43.138737	62	85.497896	87	132.323821
13	9.794280	38	44.718520	63	87.297237	88	134.268303
14	10.940408	39	46.309585	64	89.103417	89	136.217693
15	12.116500	40	47.911645	65	90.916330	90	138.171936
16	13.320620	41	49.524429	66	92.735874	91	140.130977
17	14.551069	42	51.147678	67	94.561949	92	142.094765
18	15.806341	43	52.781147	68	96.394458	93	144.063248
19	17.085095	44	54.424599	69	98.233307	94	146.036376
20	18.386125	45	56.077812	70	100.078405	95	148.014099
21	19.708344	46	57.740570	71	101.929663	96	149.996371
22	21.050767	47	59.412668	72	103.786996	97	151.983142
23	22.412494	48	61.093909	73	105.650319	98	153.974368
24	23.792706	49	62.784105	74	107.519550	99	155.970004
25	25.190646	50	64.483075	75	109.394612	100	157.970004

RECTANGULAR-POLAR CONVERSION CHART

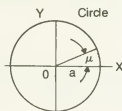
This chart quickly converts between cartesian (rectangular) and polar forms of notation. The horizontal (real) and the vertical (imaginary) coordinates are used for rectangular notations, and the angular (magnitude) and circular (angle) coordinates are used for polar notation. The same units of measurement are used for both systems. This makes conversion from one system to the other readily possible. The range of the chart can be extended by multiplying the horizontal and vertical axes by the same power of ten.

FOR EXAMPLE:

1. $2 + j3$ is equivalent to $3.6/\underline{56^\circ}$
2. $70/\underline{55^\circ}$ is equivalent to $40 + j57$
3. $6 - j3$ is equivalent to $6.7/\underline{333^\circ}$

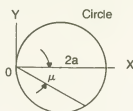


GEOMETRICAL CURVES FOR REFERENCE

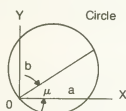


$$X^2 + Y^2 = a^2$$

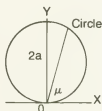
$$X = a \cos \mu, Y = a \sin \mu$$



$$r = 2a \cos \mu$$



$$r = a \cos \mu + b \sin \mu$$

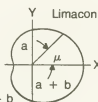


$$r = 2a \sin \mu$$



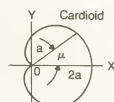
$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$$

$$X = a \cos \mu, Y = b \sin \mu$$

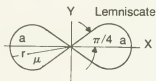


$$r = a + b \cos \mu$$

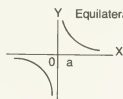
$$a > b > 0$$



$$r = a(1 + \cos \mu)$$



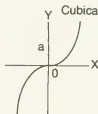
$$r^2 = a^2 \cos 2\mu$$



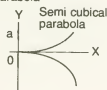
$$XY = a^2$$



$$\frac{X^2}{a^2} - \frac{Y^2}{b^2} = 1$$



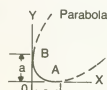
$$a^2 Y = X^3$$



$$aY^2 = X^3, a > 0$$

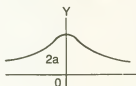


$$\frac{Y^2}{b^2} = \frac{X}{a}$$



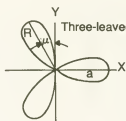
$$X^{1/2} + Y^{1/2} = a^{1/2}$$

Witch of Agnesi



$$Y(X^2 + 4a^2) = 8a^3$$

Three-leaved roses

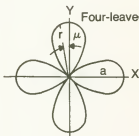


$$r = a \cos 3\mu$$

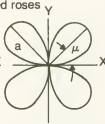


$$r = a \sin 3\mu$$

Four-leaved roses

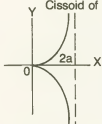


$$r = a \cos 2\mu$$



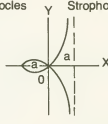
$$r = a \sin 2\mu$$

Cissoid of Diocles



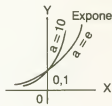
$$Y^2(2a - X) = X^3$$

Strophoid



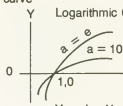
$$Y^2 = X^2 \frac{a + X}{a - X}$$

Exponential curve



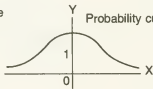
$$Y = a^x$$

Logarithmic Curve



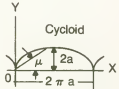
$$Y = \log_a X$$

Probability curve



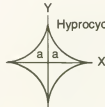
$$Y = e^{-x^2}$$

Cycloid



$$\begin{aligned} X &= a(\mu - \sin \mu) \\ Y &= a(1 - \cos \mu) \end{aligned}$$

Hypercycloid



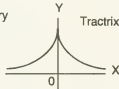
$$X^{1/3} + Y^{1/3} = a^{1/3}$$

Catenary



$$Y = a(\cosh \frac{X}{a} - 1)$$

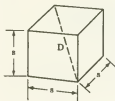
Tractrix



$$\begin{aligned} X &= \\ &\pm (a \operatorname{sech}^{-1} \frac{Y}{a} \sqrt{a^2 - Y^2}) \end{aligned}$$

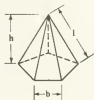
FORMULAS FOR SOLIDS

Cube



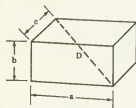
Surface Area
 $A = 6s^2$
 Volume
 $V = s^3$
 Diagonal
 $D = 1.7321s$

Right Regular Pyramid



Surface Area
 $A = \frac{1}{2}nbl + An$ (area of base)
 Volume
 $V = \frac{1}{3}Anh$

Parallelepiped



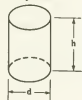
Surface Area
 $A = 2(ab + bc + ac)$
 Volume
 $V = abc$
 Diagonal
 $D = \sqrt{a^2 + b^2 + c^2}$

Right Regular Cone



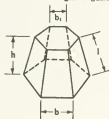
Surface Area
 $A = 1.5708d(.5d + l)$
 Volume
 $V = .2618d^2h$

Right Circular Cylinder



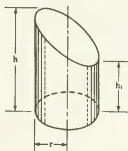
Surface Area
 $A = 1.5708d(2h + d)$
 Volume
 $V = .7854d^2h$

Frustrum of Right Regular Pyramid



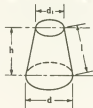
Surface Area
 $A = \frac{1}{2}l[n(b + b_1) + Ab + Ab_1]$
 Volume
 $V = \frac{1}{3}h(Ab + Ab_1 + \sqrt{AbAb_1})$

Frustrum of Right Circular Cylinder



Lateral Area
 $A = 3.1416r(h + h_1)$
 Area of Top Section
 $A = 3.1416r_1^2 + \left(\frac{h_1 - h}{2}\right)^2$
 Area of Base
 $A = 3.1416r^2$
 Volume
 $V = 1.5708r^2(h + h_1)$

Frustrum of Right Regular Cone



Surface Area
 $A = .3927[d^2 + d_1^2 + 4l(d + d_1)]$
 Volume
 $V = .2618h(d^2 + dd_1 + d_1^2)$

Sphere



Surface Area
 $A = 3.1416d^2$

Volume
 $V = .3236d^3$

Sector of Sphere



Surface Area
 $A = 1.5708 r (4h + c)$

Volume
 $V = 2.0944r^2h$

Segment of Sphere

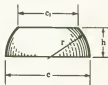


Surface Area of Top Section
 $A = 6.2832rh$ or
 $A = .7854 (4h^2 + c^2)$

Total Surface Area
 $A = 1.5708 (2h^2 + c^2)$

Volume
 $V = 1.0472h^3 (3r - h)$ or
 $V = .1318h (3c^2 + 4h^2)$

Zone of Sphere

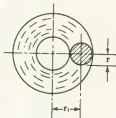


Area of Spherical Surface
 $A = 6.2832rh$

Total Surface Area
 $A = .7854 (8rh + c^2 + c^2)$

Volume
 $V = .1318h (3c^2 + 3c^2 + 4h^2)$

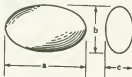
Torus



Surface Area
 $A = 39.478rr_1$

Volume
 $V = 19.739r^2r_1$

Ellipsoid



Volume
 $V = .5236abc$

Paraboloid



Volume
 $V = .3927ab^2$

SQUARES

$$\text{AREA} = a^2$$



ROUNDS

$$\text{AREA} = 0.7854d^2$$



OVALS

$$\text{AREA} = 0.7954 ab$$



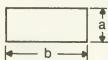
HEXAGONS

$$\text{AREA} = 3.464r^2$$



RECTANGLES

$$\text{AREA} = ab$$



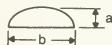
HALF ROUNDS

$$\text{AREA} = \frac{0.7854d^2}{2}$$



HALF OVALS

$$\text{AREA} = 0.7854 ab$$



OCTAGONS

$$\text{AREA} = 3.314r^2$$



RIGHT-ANGLED TRIANGLE

$$\text{AREA} = \frac{ab}{2}$$



SEGMENT OF ROUNDS

$$\text{AREA} = \frac{rl - c(r-h)}{2}$$



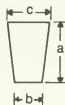
EQUILATERAL TRIANGLES

$$\text{AREA} = 0.433013b^2$$



KEYSTONES

$$\text{AREA} = \frac{a(b+c)}{2}$$



TRIANGLES



RIGHT-ANGLED

Known	Find	FORMULAS
a, c	A, B, b	$\sin A = \frac{a}{c}, \cos B = \frac{b}{c}, b = \sqrt{c^2 - a^2}$
	Area	$\frac{a^2}{2} \sqrt{c^2 - a^2}$
a, b	A, B, c	$\tan A = \frac{a}{b}, \tan B = \frac{b}{a}, c = \sqrt{a^2 + b^2}$
	Area	$\frac{ab}{2}$
A, a	B, b, c	$B = 90^\circ - A, b = a \cot A, c = \frac{a}{\sin A}$
	Area	$\frac{a^2 \cot A}{2}$
B, b	A, a, c	$B = 90^\circ - A, a = b \tan A, c = \frac{b}{\cos A}$
	Area	$\frac{b^2 \tan A}{2}$
A, c	B, a, b	$B = 90^\circ - A, a = c \sin A, b = c \cos A$
	Area	$\frac{c^2 \sin A \cos A}{2} = \frac{c^2 \sin 2A}{4}$



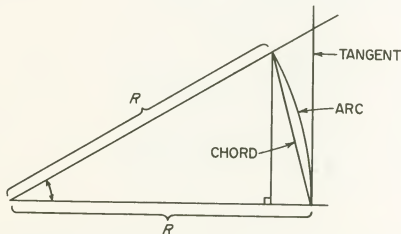
$$s = \frac{a+b+c}{2}$$

OBLIQUE-ANGLED

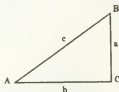
Known	Find	FORMULAS
	A	$\sin \frac{1}{2} A = \sqrt{\frac{(b-c)(b+c)}{bc}}, \cos \frac{1}{2} A = \sqrt{\frac{s(s-a)}{bc}}, \tan \frac{1}{2} A = \sqrt{\frac{(b-c)(b+c)}{s(s-a)}}$
a, b, c	B	$\sin \frac{1}{2} B = \sqrt{\frac{(a-c)(a+c)}{ac}}, \cos \frac{1}{2} B = \sqrt{\frac{s(s-b)}{ac}}, \tan \frac{1}{2} B = \sqrt{\frac{(a-c)(a+c)}{s(s-b)}}$
	C	$\sin \frac{1}{2} C = \sqrt{\frac{(a-b)(a+b)}{ab}}, \cos \frac{1}{2} C = \sqrt{\frac{s(s-c)}{ab}}, \tan \frac{1}{2} C = \sqrt{\frac{(a-b)(a+b)}{s(s-c)}}$
	Area	$\sqrt{s(s-a)(s-b)(s-c)}$
a, A, B	b, c	$b = \frac{a \sin B}{\sin A}, c = \frac{a \sin C}{\sin A}, A + B + C = 180^\circ$
	Area	$\frac{1}{2} a b \sin C = \frac{a^2 \sin B \sin C}{2 \sin A}$
a, b, A	B	$\sin B = \frac{b \sin A}{a}$
	C	$C = 180^\circ - (A + B)$
	c	$c = \frac{a \sin C}{\sin A} = \frac{b \sin C}{\sin B} = \sqrt{a^2 + b^2 - 2ab \cos C}$
	Area	$\frac{1}{2} a b \sin C = \frac{1}{2} a c \sin B = \frac{1}{2} b c \sin A$
	A	$\tan A = \frac{a \sin C}{b - a \cos C}$
	B	$B = 180^\circ - (A + C), \tan \frac{1}{2} (A - B) = \frac{a - b \cos \frac{1}{2} C}{a + b}$
a, b, C	C	$c = \frac{a \sin C}{\sin A} = \sqrt{a^2 + b^2 - 2ab \cos C}$
	Area	$\frac{1}{2} a b \sin C$
		$a^2 = b^2 + c^2 - 2bc \cos A, b^2 = a^2 + c^2 - 2ac \cos B, c^2 = a^2 + b^2 - 2ab \cos C$
		$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$

VALUES OF FUNCTIONS FOR CERTAIN ANGLES

Angle deg.	Arc	Sin	Cos	Tan	Cot	Sec	Csc	Chord.
0	0	0	+1	0	∞	+1	∞	0
30	$1/6 \pi$	1/2	$1/2\sqrt{3}$	$1/3\sqrt{3}$	$\sqrt{3}$	$2/3\sqrt{3}$	2	$\sqrt{2-\sqrt{3}}$
45	$1/4 \pi$	$1/2\sqrt{2}$	$1/2\sqrt{2}$	+1	+1	$\sqrt{2}$	$\sqrt{2}$	$\sqrt{2-\sqrt{2}}$
60	$1/3 \pi$	$1/2\sqrt{3}$	1/2	$\sqrt{3}$	$1/3\sqrt{3}$	2	$2/3\sqrt{3}$	1
90	$1/2 \pi$	+1	0	∞	0	∞	+1	$\sqrt{2}$
120	$2/3 \pi$	$1/2\sqrt{3}$	-1/2	$-\sqrt{3}$	$-1/3\sqrt{3}$	-2	$2/3\sqrt{3}$	$\sqrt{3}$
135	$3/4 \pi$	$1/2\sqrt{2}$	$-1/2\sqrt{2}$	-1	-1	$-\sqrt{2}$	$\sqrt{2}$	$\sqrt{2+\sqrt{2}}$
150	$5/6 \pi$	1/2	$-1/2\sqrt{3}$	$-1/3\sqrt{3}$	$-\sqrt{3}$	$-2/3\sqrt{3}$	2	$\sqrt{2+\sqrt{3}}$
180	π	0	-1	0	∞	-1	∞	2
210	$7/6 \pi$	-1/2	$-1/2\sqrt{3}$	$1/3\sqrt{3}$	$\sqrt{3}$	$-2/3\sqrt{3}$	-2	$\sqrt{2+\sqrt{3}}$
225	$5/4 \pi$	$-1/2\sqrt{2}$	$-1/2\sqrt{2}$	+1	+1	$-\sqrt{2}$	$-\sqrt{2}$	$\sqrt{2+\sqrt{2}}$
240	$4/3 \pi$	$-1/2\sqrt{3}$	-1/2	$\sqrt{3}$	$1/3\sqrt{3}$	-2	$-2/3\sqrt{3}$	$\sqrt{3}$
270	$3/2 \pi$	-1	0	∞	0	∞	-1	$\sqrt{2}$
300	$5/3 \pi$	$-1/2\sqrt{3}$	1/2	$-\sqrt{3}$	$-1/3\sqrt{3}$	2	$-2/3\sqrt{3}$	1
315	$7/4 \pi$	$-1/2\sqrt{2}$	$1/2\sqrt{2}$	-1	-1	$\sqrt{2}$	$-\sqrt{2}$	$\sqrt{2-\sqrt{2}}$
330	$11/6 \pi$	-1/2	$1/2\sqrt{3}$	$-1/3\sqrt{3}$	$-\sqrt{3}$	$2/3\sqrt{3}$	-2	$\sqrt{2-\sqrt{3}}$
360	2π	0	+1	0	∞	+1	∞	0



TRIGONOMETRIC FUNCTIONS



Fundamental Trigonometric Functions

$$\begin{aligned}\sin A &= \frac{a}{c} & \csc A &= \frac{c}{a} \\ \cos A &= \frac{b}{c} & \sec A &= \frac{c}{b} \\ \tan A &= \frac{a}{b} & \cot A &= \frac{b}{a}\end{aligned}$$

Functions of one angle

$$\begin{aligned}\sin^2 A + \cos^2 A &= 1 \\ \sec^2 A - \tan^2 A &= 1 \\ \csc^2 A - \cot^2 A &= 1\end{aligned}$$

Functions of the sum of two angles

$$\begin{aligned}\sin(A+B) &= \sin A \cos B + \cos A \sin B \\ \cos(A+B) &= \cos A \cos B - \sin A \sin B \\ \tan(A+B) &= \frac{\tan A + \tan B}{1 - \tan A \tan B} \\ \cot(A+B) &= \frac{\cot A \cot B - 1}{\cot B + \cot A}\end{aligned}$$

Functions of the difference of two angles

$$\begin{aligned}\sin(A-B) &= \sin A \cos B - \cos A \sin B \\ \cos(A-B) &= \cos A \cos B + \sin A \sin B \\ \tan(A-B) &= \frac{\tan A - \tan B}{1 + \tan A \tan B} \\ \cot(A-B) &= \frac{\cot A \cot B + 1}{\cot B - \cot A}\end{aligned}$$

Functions of one-half an angle

$$\begin{aligned}\sin \frac{1}{2}A &= \frac{\sin A}{2\cos \frac{1}{2}A} = \pm \sqrt{\frac{1 - \cos A}{2}} \\ \cos \frac{1}{2}A &= \frac{\sin A}{2\sin \frac{1}{2}A} = \pm \sqrt{\frac{1 + \cos A}{2}} \\ \tan \frac{1}{2}A &= \frac{1 - \cos A}{\sin A} = \pm \sqrt{\frac{1 - \cos A}{1 + \cos A}} \\ \cot \frac{1}{2}A &= \pm \sqrt{\frac{1 + \cos A}{1 - \cos A}}\end{aligned}$$

Functions of twice an angle

$$\begin{aligned}\sin 2A &= 2 \sin A \cos A = \frac{2 \tan A}{1 + \tan^2 A} \\ \cos 2A &= \cos^2 A - \sin^2 A = 1 - 2\sin^2 A \\ &= 2\cos^2 A - 1 = \frac{1 - \tan^2 A}{1 + \tan^2 A} \\ \tan 2A &= \frac{2 \tan A}{1 - \tan^2 A} = \frac{\sin 2A}{\cos 2A} \\ \cot 2A &= \frac{\cot^2 A - 1}{2 \cot A}\end{aligned}$$

Functions of three times an angle

$$\begin{aligned}\sin 3A &= 3 \sin A - 4 \sin^3 A \\ \cos 3A &= 4 \cos^3 A - 3 \cos A \\ \tan 3A &= \frac{3 \tan A - \tan^3 A}{1 - 3 \tan^2 A} \\ \cot 3A &= \frac{\cot^3 A - 3 \cot A}{3 \cot^2 A - 1}\end{aligned}$$

Functions of angles squared

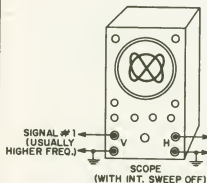
$$\begin{aligned}\sin^2 A &= \frac{1 - \cos 2A}{2} \\ \cos^2 A &= \frac{1 + \cos 2A}{2} \\ \tan^2 A &= \frac{1 - \cos 2A}{1 + \cos 2A} \\ \cot^2 A &= \frac{1 + \cos 2A}{1 - \cos 2A} \\ \sin^2 A - \sin^2 B &= \sin(A+B) \sin(A-B) \\ \cos^2 A - \sin^2 B &= \cos(A+B) \cos(A-B)\end{aligned}$$

Functions—Relationships

$$\begin{aligned}\sin A &= \frac{\cos A}{\cot A} = \frac{1}{\csc A} = \cos A \tan A = \sqrt{1 - \cos^2 A} \\ \cos A &= \frac{\sin A}{\tan A} = \frac{1}{\sec A} = \sin A \cot A = \sqrt{1 - \sin^2 A} \\ \tan A &= \frac{\sin A}{\cos A} = \frac{1}{\cot A} = \sin A \sec A \\ \cot A &= \frac{\cos A}{\sin A} = \frac{1}{\tan A} = \cos A \csc A \\ \sec A &= \frac{\tan A}{\sin A} = \frac{1}{\cos A} \\ \csc A &= \frac{1}{\sin A} = \frac{\cot A}{\cos A} \\ \sin A + \sin B &= 2 \sin \frac{1}{2}(A+B) \cos \frac{1}{2}(A-B) \\ \sin A - \sin B &= 2 \cos \frac{1}{2}(A+B) \sin \frac{1}{2}(A-B) \\ \cos A + \cos B &= 2 \cos \frac{1}{2}(A+B) \cos \frac{1}{2}(A-B) \\ \cos A - \cos B &= -2 \sin \frac{1}{2}(A+B) \sin \frac{1}{2}(A-B) \\ \tan A + \tan B &= \frac{\sin(A+B)}{\cos A \cos B} \\ \tan A - \tan B &= \frac{\sin(A-B)}{\cos A \cos B} \\ \cot A + \cot B &= \frac{\sin(A+B)}{\sin A \sin B} \\ \cot A - \cot B &= \frac{\sin(B-A)}{\sin A \sin B}\end{aligned}$$

LISSAJOUS FIGURES

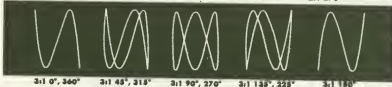
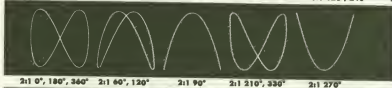
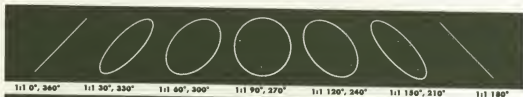
For two signals having the same frequency, the phase can be determined by measuring the major and minor axes of the ellipse. The phase angle is equal to twice the angle whose tangent is the ratio of the major axis to the minor axis. The absolute accuracy of this method is dependent upon the phase in the horizontal and vertical amplifiers of the oscilloscope being equal and the care that is taken to make the horizontal and vertical amplitudes equal.



① ② ③
 NO. LOOPS TANGENT TO HORIZ. LINE DEPENDS ON VERT. FREQ. (IN THIS CASE, 3)

①
 NO. LOOPS TANGENT TO VERT. LINE DEPENDS ON HORIZ. FREQ. (IN THIS CASE, 2)

FREQUENCY RATIO = VERT. FREQ. : HORIZ. FREQ. :: 3 : 2
 (FOR EXAMPLE, IF HORIZ. FREQ. IS 600Hz THEN VERT. FREQ. IS 900Hz)

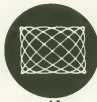




8:4



6:11



6:5



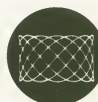
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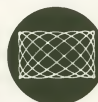
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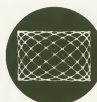
7:3



7:4



7:5



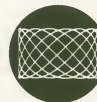
7:6



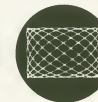
8:1



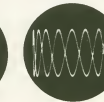
8:3



8:5



8:7



9:1



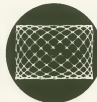
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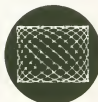
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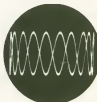
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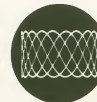
9:7



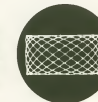
9:8



10:1



10:3



10:7

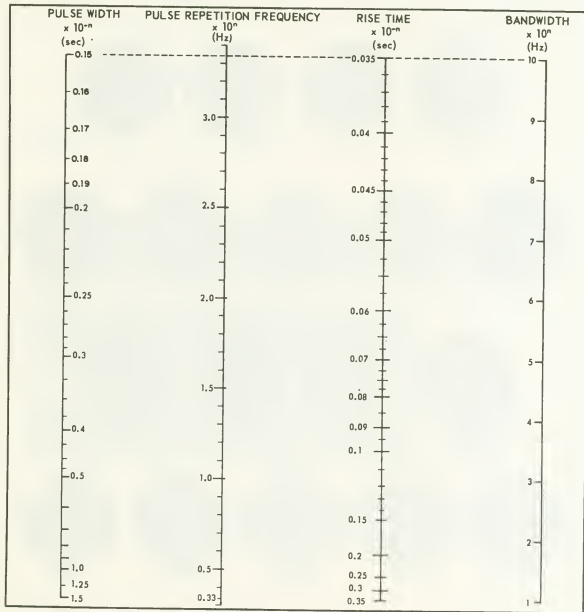


10:9

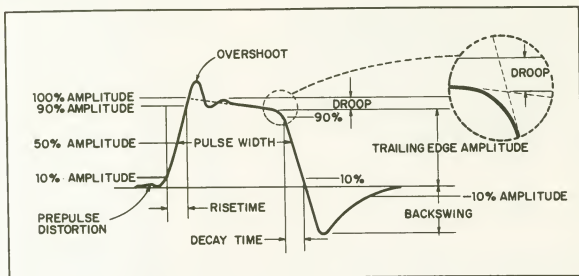
PULSE PARAMETER NOMOGRAM

This normalized nomogram relates pulse rise time, repetition frequency, and pulse width to data channel bandwidth. To use the nomogram, connect a horizontal line through the selected bandwidth. The intersection with the other columns gives maximum pulse repetition frequency, minimum pulse width, and minimum risetime. For a given bandwidth, any combination of factors below the line can be used.

FOR EXAMPLE: For a bandwidth of 10 MHz (10×10^6 Hz) the fastest risetime is 0.035×10^{-6} sec, the maximum pulse repetition frequency is 3.34×10^6 pulses per second, and the minimum pulse width is 0.15×10^{-6} sec.



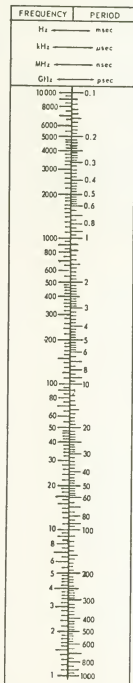
PULSE DEFINITIONS



FREQUENCY-PERIOD CONVERSION

This scale is based on the formula $f = 1/T$. It converts between the frequency (f) and the period (T) of any recurrent waveform between 1 Hz and 10,00 GHz. It is useful where a large number of conversions are required as in the case when an oscilloscope with a time-calibrated sweep is used for frequency measurements.

FOR EXAMPLE: (1) The period of a 40-MHz signal is 25 nsec. (2) The frequency of a signal with a period of 12.5 μ sec is 80 kHz.



GREEK ALPHABET

Letter		Name	Letter		Name
Small	Capital		Small	Capital	
α	Α	Alpha	ν	Ν	Nu
β	Β	Beta	ξ	Ξ	Xi
γ	Γ	Gamma	ο	Ο	Omicron
δ	Δ	Delta	π	Π	Pi
ε	Ε	Epsilon	ρ	Ρ	Rho
ζ	Ζ	Zeta	σ	Σ	Sigma
η	Η	Eta	τ	Τ	Tau
θ	Θ	Theta	υ	Υ	Upsilon
ι	Ι	Iota	φ	Φ	Phi
κ	Κ	Kappa	χ	Χ	Chi
λ	Λ	Lambda	ψ	Ψ	Psi
μ	Μ	Mu	ω	Ω	Omega

ROMAN NUMERALS

The chief symbols are I = 1; V = 5; X = 10; L = 50; C = 100; D = 500; and M = 1,000. Note that IV = 4, means 1 short of 5; IX = 9, means 1 short of ten; XL = 40, means 10 short of 50; and XC = 90, means 10 short of 100. Any symbol following one of equal or greater value adds its value—II = 2. Any symbol preceding one of greater value subtracts its value—IV = 4. When a symbol stands between two of greater value its value is subtracted from the second and the remainder is added to the first—XIV = 14; LIX = 59. Of two equivalent ways of representing a number, that in which the symbol of larger denomination preceded is preferred—XIV instead of VIX for 14.

1	I	8	VIII
2	II	9	IX
3	III	10	X
4	IV	50	L
5	V	100	C
6	VI	500	D
7	VII	1,000	M



PHASE ANGLE, TIME INTERVAL, AND FREQUENCY NOMOGRAM

Time delay, phase angle, and frequency are related by the following formula:

$$t = \frac{10^2 \theta}{36f}$$

where

t is in milliseconds


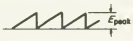
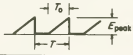


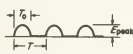



θ is in degrees

f is in hertz

FOR EXAMPLE: A phase angle of 90° between two 60-Hz wave shapes has a time interval of 4.16 msec.



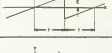

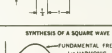
NOTE: Corresponding right-hand frequency and time scales are used together as are left-hand frequency and time scales. The range of the nomogram can be extended by multiplying the frequency scale by any power of 10 and dividing the time scale by the same power of 10.

CHARACTERISTICS OF RECURRENT WAVEFORMS—RELATIONSHIP BETWEEN PEAK, RMS, AND AVERAGE VALUES

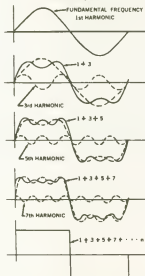
Description	Waveform	E_{rms}	E_{ave}
Alternating sine wave		$\frac{E_{peak}}{\sqrt{2}}$	$\frac{2E_{peak}}{\pi}$
Sawtooth wave		$\frac{E_{peak}}{\sqrt{3}}$	$\frac{E_{peak}}{2}$
Clipped sawtooth wave		$E_{peak} \sqrt{\frac{T_0}{3T}}$	$\frac{E_{peak} T_0}{2T}$
Square wave		$E_{peak} \sqrt{\frac{1}{2}}$	$\frac{E_{peak}}{2}$
Rectified sine wave		$\frac{E_{peak}}{\sqrt{2}}$	$\frac{2E_{peak}}{\pi}$
Clipped sine wave		$E_{peak} \sqrt{\frac{T_0}{2T}}$ if $T = T_0$ or $\frac{E_{peak}}{2}$	$\frac{E_{peak}}{\pi}$
Alternating square wave		E_{peak}	E_{peak}
Rectangular wave		$E_{peak} \sqrt{\frac{T_0}{T}}$	$\frac{E_{peak} T_0}{T}$
Triangular wave		$\frac{E_{peak}}{\sqrt{3}}$	$\frac{E_{peak}}{2}$

FOURIER CONTENT OF COMMON PERIODIC WAVEFORMS

The Fourier content of five common periodic waveforms, out to the seventh harmonic, is given in this table. Magnitudes only are tabulated—not phase relationships. The magnitudes are those of the voltage waveform, followed by the corresponding percentage values in parentheses. If energy content is desired, these values must be squared. Note that there are no even harmonics present in any of the symmetrical waveforms.

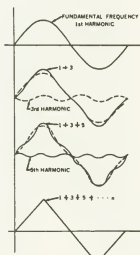
Waveform	Name	Harmonic Composition (magnitude)						
		Fund.	2nd	3rd	4th	5th	6th	7th
	Square Wave	$\frac{4}{\pi} E$ (127%)	0 (0%)	$\frac{4}{3\pi} E$ (42.5%)	0 (0%)	$\frac{4}{5\pi} E$ (25.5%)	0 (0%)	$\frac{4}{7\pi} E$ (18.2%)
	Triangular Wave	$\frac{8}{\pi^2} E$ (81%)	0 (0%)	$\frac{8}{9\pi^2} E$ (9%)	0 (0%)	$\frac{8}{25\pi^2} E$ (3.2%)	0 (0%)	$\frac{8}{49\pi^2} E$ (1.6%)
	Sawtooth Wave	$\frac{2}{\pi} E$ (63.6%)	$\frac{1}{\pi} E$ (31.8%)	$\frac{2}{3\pi} E$ (21.2%)	$\frac{1}{2\pi} E$ (15.9%)	$\frac{2}{5\pi} E$ (12.7%)	$\frac{1}{3\pi} E$ (10.6%)	$\frac{2}{7\pi} E$ (9.1%)
	Half-Wave Rectifier Output	$\frac{1}{\pi} E$ (31.8%)	$\frac{2}{3\pi} E$ (21.2%)	0 (0%)	$\frac{2}{15\pi} E$ (4.2%)	0 (0%)	$\frac{2}{35\pi} E$ (1.8%)	0 (0%)
	Full-Wave Rectifier Output	$\frac{2}{\pi} E$ (63.6%)	$\frac{4}{3\pi} E$ (42.3%)	0 (0%)	$\frac{4}{15\pi} E$ (8.5%)	0 (0%)	$\frac{4}{35\pi} E$ (3.6%)	0 (0%)

SYNTHESIS OF A SQUARE WAVE



$$\left(\sin x + \frac{1}{3} \sin 3x + \frac{1}{5} \sin 5x + \frac{1}{7} \sin 7x + \dots \right) \sin x$$

SYNTHESIS OF A TRIANGULAR WAVE

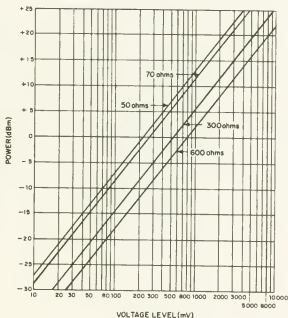


$$\sin x - \frac{1}{9} \sin 3x + \frac{1}{25} \sin 5x - \frac{1}{49} \sin 7x + \dots - \frac{1}{n^2} \sin nx$$

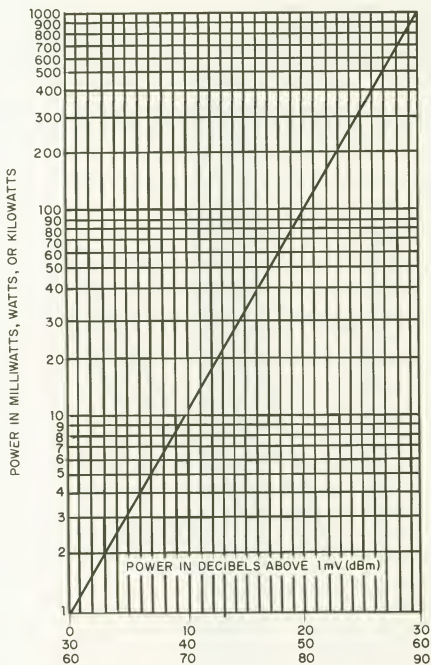
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CONVERSIONS FROM DB AND DBM TO VOLTAGE AND POWER RATIOS, AND FROM DBM TO POWER AND VOLTAGE LEVELS

Ratio in db or dBm	Relationships for Either dB or dBm				Relationships for dBm Only			
	Voltage Ratio (per unit)	Power Ratio (per unit)	Voltage Ratio (per cent)	Power Ratio (per cent)	Power (Referred to 1 mW)	Voltage Across 50 ohms	Voltage Across 70 ohms	Voltage Across 600 ohms
+120.0	10 ³	10 ³	—	—	10 GW	224 kV	265 kV	775 kV
+80.0	10 ²	10 ²	—	—	100 kW	2.24 kV	2.65 kV	7.75 kV
+60.0	10 ¹	10 ¹	—	—	1 kW	224 V	265 V	775 V
+50.0	316	10 ^{1/2}	—	—	100 W	70.7 V	83.7 V	245 V
+40.0	100	10 ¹	—	—	10.0 W	22.4 V	26.5 V	77.5 V
+30.0	31.6	10 ^{1/2}	31.60	—	1.00 W	7.07 V	8.37 V	24.5 V
+20.0	10.00	100.0	1000	—	100 mW	2.24 V	2.65 V	7.75 V
+17.0	7.08	30.1	708	5010	50 mW	1.59 V	1.88 V	5.49 V
+13.98	5.00	25.0	500	2500	25 mW	1.12 V	1.325 V	3.875 V
+12.04	4.00	16.0	400	1600	16 mW	895 mV	1.060 V	3.100 V
+9.54	3.00	9.00	300	900	9 mW	672 mV	795 mV	2.325 V
+6.02	2.00	4.00	200	400	4 mW	448 mV	530 mV	1.550 V
+3.01	1.41	2.00	141	200	2 mW	316 mV	374 mV	1.092 V
+2.00	1.26	1.58	126	158	1.26 mW	282 mV	334 mV	976 mV
+1.00	1.12	1.26	112	126	1.12 mW	251 mV	297 mV	868 mV
0.00	1.00	1.000	100	100	1.00 mW	224 mV	265 mV	775 mV
-1.00	0.893	0.793	89.3	79.3	790 μW	201 mV	237 mV	693 mV
-2.00	0.793	0.633	79.3	63.3	630 μW	178 mV	215 mV	615 mV
-3.01	0.707	0.500	70.7	50.0	500 μW	158 mV	187 mV	548 mV
-6.02	0.500	0.250	50.0	25.0	250 μW	114 mV	133 mV	388 mV
-9.54	0.333	0.111	33.3	11.1	110 μW	74.5 mV	88.3 mV	258 mV
-12.04	0.250	0.063	25.0	6.3	62.5 μW	56.0 mV	66.2 mV	194 mV
-13.98	0.200	0.040	20.0	4.0	40.0 μW	44.8 mV	53.0 mV	155 mV
-17.0	0.141	0.020	14.1	2.0	20.0 μW	31.6 mV	37.4 mV	109 mV
-20.0	0.100	0.010	10.0	1.0	10.0 μW	22.4 mV	26.5 mV	77.5 mV
-30.0	0.032	0.001	3.16	0.1	1.0 μW	7.07 mV	8.37 mV	24.5 mV
-40.0	0.010	10 ⁻⁴	1.000	0.01	100 nW	2.24 mV	2.65 mV	7.75 mV
-50.0	0.0032	10 ⁻⁵	0.316	0.001	10 nW	707 μV	837 μV	2.45 mV
-60.0	0.001	10 ⁻⁶	0.100	10 ⁻⁴	1 nW	224 μV	265 μV	775 μV
-80.0	10 ⁻⁴	10 ⁻⁸	0.010	10 ⁻⁶	10 pW	22.4 μV	26.5 μV	77.5 μV
-120.0	10 ⁻⁶	10 ⁻¹²	—	—	1 fW	224 nV	265 nV	775 nV



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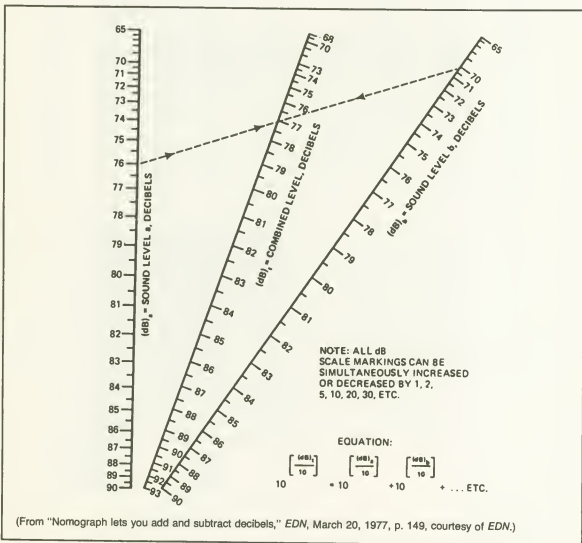
DECIBEL NOMOGRAMS

The nomogram below is based on the equation shown and makes possible rapid addition or subtraction of two or more dB levels.

For off-scale levels 1, 2, 5, 10, 20, 30, etc., can be added or subtracted, simultaneously, to all nomograph scale values. For more than two levels, add any two, and to the first sum add the third, etc.

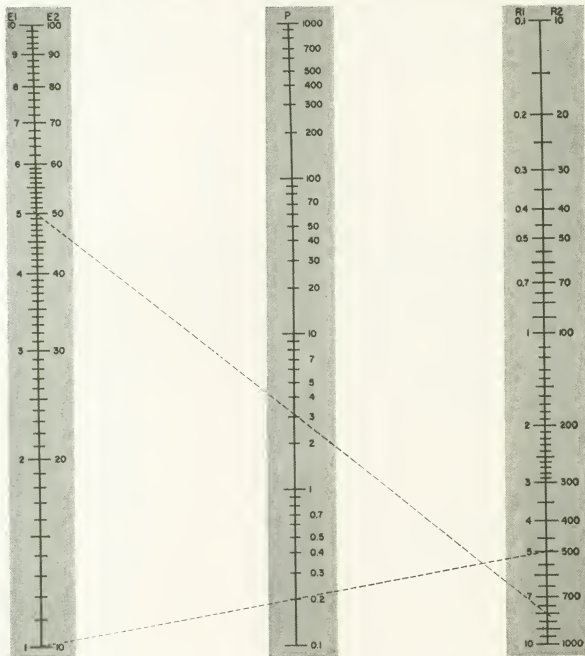
FOR EXAMPLE: (1) What is the combined sound power level of 70, 76 and 80.5 dB? Align $(dB)_a = 76$ with $(dB)_b = 70$ and read $(dB)_t = 77.0$; align $(dB)_a = 77.0$ with $(dB)_b = 80.5$ and read the answer as $(dB)_t = 82.1$ dB.

(2) When a fan is on, the sound pressure level equals 68 dB and 64 dB with the fan off. What is the sound pressure level of the fan? To extend the range of the nomogram, subtract 10 from all scale values; align $(dB)_t = 68 = 78 - 10$ with $(dB)_a = 64 = 74 - 10$, and read $(dB)_b = 75.8 - 10 = 65.8$ dB = fan sound pressure level.

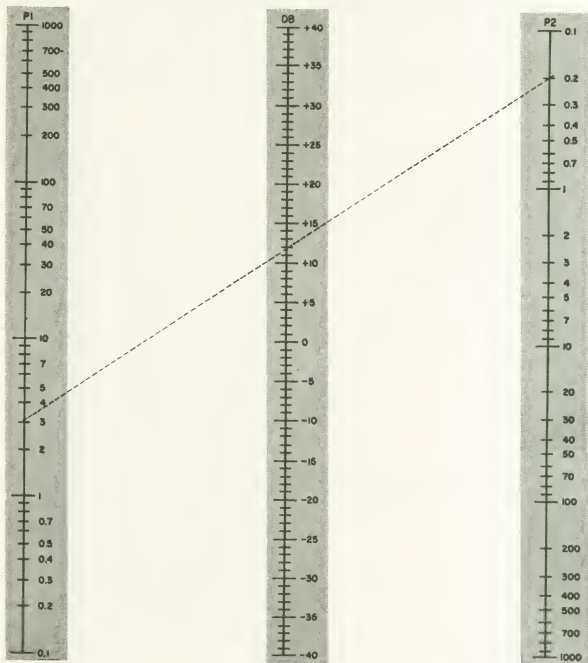


DECIBEL NOMOGRAPHS

With the nomograph below and the one on the next page dB gain or loss of any equipment can be determined (even if input and output impedances differ) if input and output voltages and resistances can be measured. The nomograms cover a power range of 10,000 to 1, a voltage range of 100 to 1, and a decibel range from +40 to -40 dB. Voltage and resistance scales of nomogram 1 bearing the same suffix are used together.



FOR EXAMPLE: Determine the gain of an amplifier that produces an output of 5 V across 8 ohms with a 10-V signal applied to its 500-ohm input. From nomogram 1, the input power is 0.2 W and the output power is 3.1 W. Connecting input and output power on nomogram 11 shows the amplifier gain to be slightly less than 12 dB.



LETTER SYMBOLS FOR QUANTITIES USED IN ELECTRICAL SCIENCE AND ELECTRICAL ENGINEERING

Extracted from IEEE Standard No. 280

The tables that follow list quantities grouped in several categories, and give quantity symbols, units based on the International System,* and unit symbols.

Those quantity symbols that are separated by a comma are alternatives on equal standing. Where two symbols for a quantity are separated by three dots (...), the second is a reserve symbol, which is to be used only where there is specific need to avoid a conflict. As a rule the tables do not indicate the vectorial or tensorial character that some of the quantities may have.

The International System of Units (Système International d'Unités) is the coherent system of units based on the following units and quantities:

Unit	Quantity
meter	length
kilogram	mass
second	time
ampere	electric current
kelvin	temperature
candela	luminous intensity
radian	plane angle
steradian	solid angle

This system was named (and given the international designation SI) in 1960 by the Conférence Générale des Poids et Mesures (CGPM). The SI units include as subsystems the MKS system of units, which covers mechanics, and the MKSA or Giorgi system, which covers mechanics, electricity, and magnetism.

*The name of the unit is given as a further guide to the definition of the symbol. A quantity shall be represented by the standard letter symbol appearing in the table regardless of the system of units in which the quantity is expressed.

Item	Quantity	Quantity Symbol ^a	Unit Based on International System	Unit Symbol	Remarks
1. Space and Time					
	angle, plane	$\alpha, \beta, \gamma, \delta, \Phi, \psi$	radian	rad	Other Greek letters are permitted where no conflict results.
	angle, solid	$\Omega \dots \omega$	steradian	sr	
	length	l	meter	m	
	breadth, width	b	meter	m	
	height	h	meter	m	
	thickness	d, δ	meter	m	
	radius	r	meter	m	
	diameter	d	meter	m	
	length of path	s	meter	m	
	line segment				
	wavelength	λ	meter	m	$\sigma = 1/\lambda$ The symbol $\hat{\nu}$ is used in spectroscopy.
	wave number	$\sigma \dots \hat{\nu}$	reciprocal meter	m ⁻¹	
	circular wave number	k	radian per meter	rad/m	$k = 2\pi/\lambda$
	angular wave number				
	area	$A \dots S$	square meter	m ²	
	volume	V, v	cubic meter	m ³	
	time	t	second	s	
	period	T	second	s	
	time of one cycle				

Item	Quantity	Quantity Symbol ^a	Unit Based on International System	Unit Symbol	Remarks
	time constant	$\tau \dots T$	second	s	The name <i>cycle per second</i> is also used for this unit. The symbol for the unit <i>cycle per second</i> is <i>c/s</i> ; the use of <i>cps</i> as a symbol is deprecated. The symbol <i>f</i> is used in circuit theory, sound, and mechanics; <i>v</i> is used in optics and quantum theory.
	frequency	$f \dots \nu$	hertz	Hz	
	speed of rotation	n	revolution per second	r/s	
	rotational frequency				
	angular frequency	ω	radian per second	rad/s	$\omega = 2\pi f$
	angular velocity	ω	radian per second	rad/s	
	complex (angular) frequency	$p \dots s$	reciprocal second	s^{-1}	$p = -\delta + j\omega$
	oscillation constant				
	angular acceleration	a	radian per second squared	rad/s ²	
	velocity	v	meter per second	m/s	
	speed of propagation	c	meter per second	m/s	In vacuum, c_0 ; see 8.1.
	speed of electromagnetic waves				
	acceleration (linear)	a	meter per second squared	m/s ²	
	acceleration of free fall	g	meter per second squared	m/s ²	Standard value, g_N ; see 8.10.
	gravitational acceleration				
	damping coefficient	δ	neper per second	Np/s	If F is a function of time given by $F = Ae^{-\delta t} \sin(2\pi t/T)$,

^aCommas separate symbols on equal standing. Where two symbols are separated by three dots the second is a reserve symbol and is to be used only when there is specific need to avoid a conflict. See Introduction to the Tables.

	logarithmic decrement	Λ	(numeric)		then δ is the damping coefficient. $\Lambda = T\delta$, where T and δ are as given in the equation of 1.28.
	attenuation coefficient	α	neper per meter	Np/m	
	phase coefficient	β	radian per meter	rad/m	
	propagation coefficient	γ	reciprocal meter	m^{-1}	$\gamma = \alpha + j\beta$.
2. Mechanics ^b					
	mass	m	kilogram	kg	
	(mass) density	ρ	kilogram per cubic meter	kg/m ³	Mass divided by volume.
	momentum	p	kilogram meter per second	kg · m/s	
	moment of inertia	I, J	kilogram meter squared	kg · m ²	
	second (axial) moment of area	I, I_a	meter to the fourth power	m ⁴	Quantities 2.4a and 2.4b should be distinguished from 2.4.

Item	Quantity	Quantity Symbol ^a	Unit Based on International System	Unit Symbol	Remarks
	second (polar) moment of area	J, I_p	meter to the fourth power	m^4	They have often been given the name "moment of inertia."
	force	F	newton	N	
	weight	W	newton	N	Varies with acceleration of free fall. Weight divided by volume.
	weight density	γ	newton per cubic meter	N/m^3	
	moment of force	M	newton meter	$N \cdot m$	The name <i>pascal</i> has been suggested for this unit.
	torque	T, \dots, M	newton meter	$N \cdot m$	
	pressure	p	newton per square meter	N/m^2	
	normal stress	σ	newton per square meter	N/m^2	
	shear stress	τ	newton per square meter	N/m^2	Lateral contraction divided by elongation. $E = \sigma/\epsilon$
	stress tensor	σ	newton per square meter	N/m^2	
	linear strain	ϵ	(numeric)		
	shear strain	γ	(numeric)		
	strain tensor	ϵ	(numeric)		$G = \tau/\gamma$
	volume strain	θ	(numeric)		
	Poisson's ratio	μ, ν	(numeric)		
	Young's modulus	E	newton per square meter	N/m^2	
	modulus of elasticity	G	newton per square meter	N/m^2	$K = -p/\theta$
	shear modulus	G	newton per square meter	N/m^2	
	modulus of rigidity	K	newton per square meter	N/m^2	U is recommended in thermodynamics for internal energy and for blackbody radiation.
	bulk modulus	K	newton per square meter	N/m^2	
	work	W	joule	J	
	energy	E, W	joule	J	

^aThe units and corresponding unit symbols are included for use in electrical science and electrical engineering. In mechanics and mechanical engineering other units and corresponding unit symbols are also used. (USAS Y10.3 now being revised.)

	energy (volume) density	w	joule per cubic meter	J/m^3	Rate of energy transfer. $W = J/s$
	power	P	watt	W	
	efficiency	η	(numeric)		In 1967 the CGPM voted to give the name <i>kelvin</i> to the SI unit of temperature, which was formerly called <i>degree Kelvin</i> , and to assign it the symbol K (without the symbol °).
3. Heat ^c	absolute temperature	T, \dots, θ	kelvin	K	
	thermodynamic temperature				

Item	Quantity	Quantity Symbol ^a	Unit Based on International System	Unit Symbol	Remarks
temperature customary temperature	$t \dots \theta$		degree Celsius	$^{\circ}\text{C}$	The symbol $^{\circ}\text{C}$ is printed without space between $^{\circ}$ and the letter that follows. The word <i>centigrade</i> has been abandoned as the name of a temperature scale. The units of temperature interval or difference are identical on the Kelvin and Celsius scales. The name kelvin and symbol K were adopted by the CGPM. The name <i>degree</i> and the symbol <i>deg</i> are also used. When it is necessary to distinguish between the Fahrenheit degree and the Celsius degree, the symbols <i>deg F</i> and <i>deg C</i> may be used.
heat	Q		joule	J	
internal energy	U		joule	J	
heat flow rate	$\Phi \dots q$		watt	W	Heat crossing a surface divided by time.
temperature coefficient	α		reciprocal kelvin	K^{-1}	A temperature coefficient is not completely defined unless the quantity that changes is specified (e.g., resistance, length, pressure). The pressure (temperature) coefficient is designated by β ; the cubic expansion (temperature) coefficient, by α , β , or γ .
thermal diffusivity	a		square meter per second	m^2/s	

^aThe units and corresponding unit symbols are included for use in electrical science and engineering. In mechanical engineering other units and corresponding unit symbols are also used. (Cf. USAS Y10.4.)

thermal conductivity	$\lambda \dots k$	watt per meter kelvin	$\text{W}/(\text{m} \cdot \text{K})$	
thermal conductance	G_{θ}	watt per kelvin	W/K	
thermal resistivity	ρ_{θ}	meter kelvin per watt	$\text{m} \cdot \text{K}/\text{W}$	
thermal resistance	R_{θ}	kelvin per watt	K/W	
thermal capacitance	C_{θ}	joule per kelvin	J/K	
heat capacity				
thermal impedance	Z_{θ}	kelvin per watt	K/W	
specific heat capacity	c	joule per kelvin kilogram	$\text{J}/(\text{K} \cdot \text{kg})$	Heat capacity divided by mass.

Item	Quantity	Quantity Symbol ^a	Unit Based on International System	Unit Symbol	Remarks
	entropy	S	joule per kelvin	J/K	Entropy divided by mess.
	specific entropy	s	joule per kelvin kilogram	J/(K · kg)	
	enthalpy	H	joule	J	
4. Radiation and Light	radiant intensity	$I \dots I_e$	watt per steradian	W/sr	The symbol U is used for the special case of blackbody radiant energy.
	radiant power	$P, \Phi \dots \Phi_e$	watt	W	
	radiant flux	$W, Q \dots Q_e$	joule	J	
	radiant energy				
	radiance	$L \dots L_e$	watt per steradian square meter	W/(sr · m ²)	
	radiant exitance	$M \dots M_e$	watt per square meter	W/m ²	
	irradiance	$E \dots E_e$	watt per square meter	W/m ²	
	luminous intensity	$I \dots I_v$	candela	cd	
	luminous flux	$\Phi \dots \Phi_v$	lumen	lm	
	quantity of light	$Q \dots Q_v$	lumen second	lm · s	
	luminance	$L \dots L_v$	candela per square meter	cd/m ²	The name <i>nit</i> is sometimes used for this unit.
	luminous exitance	$M \dots M_v$	lumen per square meter	lm/m ²	
	illuminance	$E \dots E_v$	lux	lx	
	illumination				
	luminous efficacy	$K(\lambda)$	lumen per watt	lm/W	
	total luminous efficacy	K, K_t	lumen per watt	lm/W	
	refractive index	n	(numeric)		
	index of refraction				
	emissivity	$\epsilon(\lambda)$	(numeric)		
					(λ) is not part of the basic symbol but indicates that the emissivity is a function of wavelength.
	total emissivity	ϵ, ϵ_t	(numeric)		
	absorptance	$a(\lambda)$	(numeric)		
	transmittance	$\tau(\lambda)$	(numeric)		
	reflectance	$\rho(\lambda)$	(numeric)		
5. Fields and Circuits	electric charge	Q	coulomb	C	
	quantity of electricity				

Item	Quantity	Quantity Symbol ^d	Unit Based on International System	Unit Symbol	Remarks
	linear density of charge	λ	coulomb per meter	C/m	
	surface density of charge	σ	coulomb per square meter	C/m ²	
	volume density of charge	ρ	coulomb per cubic meter	C/m ³	
	electric field strength	$E \dots K$	volt per meter	V/m	
	electrostatic potential	$V \dots \phi$	volt	V	
	potential difference				
	retarded scalar potential	V_r	volt	V	
	voltage	$V, E \dots U$	volt	V	
	electromotive force				
	electric flux	Ψ	coulomb	C	
	electric flux density (electric) displacement	D	coulomb per square meter	C/m ²	
	capacitance				
	permittivity	ϵ	fared per meter	F/m	Of vacuum, ϵ_0 .
	absolute permittivity				
	relative permittivity	ϵ_r, κ	(numeric)		
	relative permittivity				
	dielectric constant				
	complex relative permittivity	ϵ_r^*, κ^*	(numeric)		$\epsilon_r^* = \epsilon_r' - j\epsilon_r''$ ϵ_r'' is positive for lossy materials. The complex absolute permittivity ϵ^* is defined in analogous fashion.
	complex relative permittivity				
	complex dielectric constant				
	electric susceptibility	$\chi_0 \dots \epsilon_i$	(numeric)		$\chi_0 = \epsilon_r - 1$
	electrization	$E_1 \dots K_1$	volt per meter	V/m	$E_1 = (D/1_0) - E$
	electric polarization	P	coulomb per square meter	C/m ²	$P = D - 1_0 E$
	electric dipole moment	p	coulomb meter	C · m	
	(electric) current	I	ampere	A	
	current density	$J \dots S$	ampere per square meter	A/m ²	
	linear current density	$A \dots a$	ampere per meter	A/m	Current divided by the breadth of the conducting sheet.
	magnetic field strength	H	ampere per meter	A/m	
	magnetic (scalar) potential	U, U_m	ampere	A	
	magnetic potential difference				
	magnetomotive force	$F, F_m \dots \mathcal{F}$	ampere	A	
	magnetic flux	Φ	weber	Wb	
	magnetic flux density	B	tesla	T	$T = \text{Wb/m}^2$

Item	Quantity	Quantity Symbol ¹	Unit Based on International System	Unit Symbol	Remarks
	magnetic induction	Λ	weber	Wb	
	magnetic flux linkage	Λ	weber per meter	Wb/m	
	(magnetic) vector potential	A_r	weber per meter	Wb/m	
	retarded (magnetic) vector potential	μ	henry per meter	H/m	Of vacuum, μ_v .
	(magnetic) permeability	μ_t	(numeric)		
	absolute permeability	μ_0	(numeric)		
	relative (magnetic) permeability	μ_r^*	(numeric)		$\mu_v^* = \mu_t^* - j\mu_r^{**}$ μ_r^* is positive for lossy materials. The complex absolute permeability μ^* is defined in analogous fashion.
	complex relative permeability	μ_r^*	(numeric)		$X_m = \mu_r - 1$
	magnetic susceptibility	$X_m \dots \mu_i$	(numeric)		
	reluctivity	ν	meter per henry	m/H	$\nu = 1/\mu$
	magnetization	H_i, M	ampere per meter	A/m	$H_i = (B/\mu_m) - H$
	magnetic polarization	J, B_i	tesla	T	$J = B - \mu_m H$
	intrinsic magnetic flux density				
	magnetic (free) moment	m	ampere meter squared	A · m ²	The vector product $m \times B$ is equal to the torque.
	capacitance	C	farad	F	
	elastance	S	reciprocal farad	F ⁻¹	$S = 1/C$
	(self) inductance	L	henry	H	
	reciprocal inductance	l^*	reciprocal henry	H ⁻¹	
	mutual inductance	L_{ij}, M_{ij}	henry	H	If only a single mutual inductance is involved, M may be used without subscripts.
	coupling coefficient	$k \dots \kappa$	(numeric)		$k = L_{ij}/(L_i L_j)^{-1/2}$
	leakage coefficient	σ	(numeric)		$\sigma = 1 - k^2$
	number of turns (in a winding)	N, n	(numeric)		
	number of phases	m	(numeric)		
	turns ratio	$n \dots n_s$	(numeric)		
	transformer ratio	a	(numeric)		Square root of the ratio of secondary to primary self inductance is high, $a = n_s$.
	resistance	R	ohm	Ω	
	resistivity	ρ	ohm meter	$\Omega \cdot m$	
	volume resistivity				
	conductance	G	mho	mho	$G = \text{Re } Y$ The IEC has adopted

Item	Quantity	Quantity Symbol ^d	Unit Based on International System	Unit Symbol	Remarks
	conductivity	γ, σ	mho per meter	mho/m	the name <i>siemens</i> (S) for this unit. The CGPM has not yet adopted a name. $\gamma = 1/\rho$ The symbol σ is used in field theory, as γ is there used for the propagation coefficient. See remark for 5.50.
	reluctance	$R, R_m \dots \mathcal{R}$	reciprocal henry	H ⁻¹	Magnetic potential difference divided by magnetic flux. $P_m = 1/R_m$ $Z = R + jX$
	permeance	$P, P_m \dots \mathcal{P}$	henry	H	
	impedance	Z	ohm	Ω	
	reactance	X	ohm	Ω	
	capacitive reactance	X_C	ohm	Ω	For a pure capacitance, $X_C = -1/\omega C$
	inductive reactance	X_L	ohm	Ω	For a pure inductance, $X_L = \omega L$
	quality factor	Q	(numeric)		$Q = \frac{2\pi (\text{peak energy stored})}{(\text{energy dissipated per cycle})}$ For a simple reactor, $Q = |X|/R$ $Y = 1/Z = G + jB$
	admittance	Y	mho	mho	See remark for 5.50.
	susceptance	B	mho	mho	$B = \text{Im } Y$
	loss angle	δ	radian	radian	See remark for conductance.
	active power	P	watt	W	$\delta = \arctan (R/|X|)$
	reactive power	$Q \dots P_q$	var	var	
	apparent power	$S \dots P_s$	voltampere	VA	
	power factor	$\cos \phi \dots F_p$	(numeric)		
	reactive factor	$\sin \phi \dots F_q$	(numeric)		
	input power	P_i	watt	W	
	output power	P_o	watt	W	
	Poynting vector	S	watt per square meter	W/m ²	
	characteristic impedance	Z_0	ohm	Ω	
	surge impedance				
	intrinsic impedance of a medium	η	ohm	Ω	
	voltage standing-wave ratio	S	(numeric)		
	resonance frequency	f_r	hertz	Hz	The name <i>cycle per second</i> (c/s) is also used for this unit.
	critical frequency	f_c	hertz	Hz	
	cutoff frequency				
	resonance angular frequency	ω_r	radian per second	rad/s	
	critical angular frequency	ω_c	radian per second	rad/s	
	cutoff angular frequency				
	resonance wavelength	λ_r	meter	m	
	critical wavelength	λ_c	meter	m	
	cutoff wavelength				
	wavelength in a guide	λ_g	meter	m	

Item	Quantity	Quantity Symbol ^d	Unit Based on International System	Unit Symbol	Remarks
	hysteresis coefficient	k_h	(numeric)		
	eddy-current coefficient	k_e	(numeric)		
	phase angle	ϕ, θ	radian	rad	
6. Electronics and	phase difference				
	Telecommunication carrier frequency	f_c	hertz	Hz	The name <i>cycle per second (c/s)</i> is also used for this unit.
	instantaneous frequency	f, f_i	hertz	Hz	
	intermediate frequency	f_i, f_{if}	hertz	Hz	
	modulation frequency	f_m	hertz	Hz	
	pulse repetition frequency	f_p	hertz	Hz	
	frequency deviation	f_d	hertz	Hz	
	Doppler frequency shift	f_D	hertz	Hz	
	pulse duration	t_p	second	s	
	rise time (of a pulse)	t_r	second	s	
	fall time (of a pulse)	t_f	second	s	
	decay time (of a pulse)				
	duty factor	D	(numeric)		$D = t_p f_p$
	pulse duty factor				
	phase propagation time	t_ϕ	second	s	
	group propagation time	t_g	second	s	
	duration of a signal element	τ	second	s	
	signaling speed	$1/\tau$	baud	Bd	
	cathode-heating time	t_k	second	s	
	deionization time	t_d	second	s	
	ionization time	t_i	second	s	
	form factor	k_f	(numeric)		
	peak factor	k_{pk}	(numeric)		
	distortion factor	d	(numeric)		
	modulation factor (AM)	m	(numeric)		
	modulation index (FM)	η	(numeric)		
	signal power	P_s, S	watt	W	
	noise power	P_n, N	watt	W	
	noise-power density	N_o	watt per hertz	W/Hz	
	energy of a signal element	E	joule	J	
	signal-to-noise power, ratio ^o	$R, S/N$	(numeric)		$R = P_s/P_n$
	elementary signal-to-noise ratio ^o	R, R_e	(numeric)		$R_e = E/N_o$
	gain (power) ^o	G	(numeric)		
	amplification (current or voltage) ^o	A	(numeric)		
	noise factor ^o	F	(numeric)		
	noise figure				

Item	Quantity	Quantity Symbol ^a	Unit Based on International System	Unit Symbol	Remarks
bandwidth	β		hertz	Hz	See remark for carrier frequency.
feedback transfer ratio	β		(numeric)		
critical frequency of an ionized layer	f_c		hertz	Hz	See remark for carrier frequency.
plasma frequency	f_p		hertz	Hz	See remark for carrier frequency.
ion (number)	n^+, n^-		ion per cubic meter	m^{-3}	
density					
mobility (of a charge carrier in a medium)	μ		square meter per volt second	$m^2/(V \cdot s)$	
rate of production of electrons per unit volume	q		electron per cubic meter second	$m^{-3} s^{-1}$	
recombination coefficient	α		cubic meter per second	m^3/s	
effective attachment coefficient	β		reciprocal second	s^{-1}	
μ -factor	μ_{ij}		(numeric)		$\mu_{ij} = |\partial v_i / \partial v_j|$ where v_j and v_i are the voltages of the j th and i th electrodes, and the current to the i th electrode and all electrode voltages other than v_j and v_i are held constant.
amplification factor	μ		(numeric)		The amplification factor is the μ -factor for the anode and control-grid electrodes.
interelectrode transmittance	γ_{ij}		mho	mho	See remark for conductance.
interelectrode transconductance	g_{ij}		mho	mho	The real part of the interelectrode transmittance. See conductance.
mutual conductance transconductance	g_m, g_{eg}		mho	mho	The mutual conductance is the control-grid-to-anode transconductance. See conductance.
conversion transconductance	g_c		mho	mho	Transconductance defined for a heterodyne conversion transducer. See conductance.
plate resistance	r_a		ohm	Ω	
anode resistance					
anode dissipation power	P_a		watt	W	
grid dissipation power	P_g		watt	W	
saturation current of a cathode	I_s		ampere	A	

Item	Quantity	Quantity Symbol ^d	Unit Based on International System	Unit Symbol	Remarks
secondary-emission ratio	δ		(numeric)		
temperature of mercury condensate	T_{Hg}		kelvin	K	
radiant sensitivity of a phototube, dynamic	s		ampere per watt	A/W	
radiant sensitivity of a phototube, static	S		ampere per watt	A/W	
luminous sensitivity of a phototube, dynamic	s_v		ampere per lumen	A/lm	
luminous sensitivity of a phototube, static	S_v		ampere per lumen	A/lm	
Subscripts, electronic tubes					
anode			a		
cathode			k		
grid			g		
heater			h		
filament (emitting)			f		
fluorescent screen or target			t		
external conducting coating			M		
internal conducting coating			m		
deflector electrode			x or y		
internal shield			s		
wave-retardation electrode			wr		
beam-forming plate			bp		
switch, moving contact			cm		
switch, fixed contact			cf		
Subscripts, semiconductor devices					
emitter terminal			E, e		
base terminal			B, b		
collector terminal			C, c		
anode			A, a		
cathode			K, k		
control terminal (gate)			G, g		
junction (general)			J, j		
7. Machines and Power Engineering					
synchronous speed (of rotation)	n_1		revolution per second	r/s	
synchronous angular frequency	ω_1		radian per second	rad/s	
slip	s		(numeric)		
number of poles	$p, 2p$		(numeric)		The IEC gives p for the number of pairs of poles, although p has been widely used in the U.S. for the number of poles. Where ambiguity may occur, the intended meaning should be indicated.
pole strength	$p \dots m$		weber	Wb	

LETTER SYMBOLS FOR UNITS USED IN ELECTRICAL SCIENCE AND ELECTRICAL ENGINEERING

Extracted from IEEE Standard No. 260

The use of unit symbols, instead of the spelled-out names of the units, is frequently desirable where space is restricted. Their use presupposes that the reader will find them intelligible. If there is any doubt that the reader will understand a symbol, the name of the unit should be written in full. When an unfamiliar unit symbol is first used in text, it should be followed by its name in parentheses; only the symbol need be used thereafter. Explanatory notes or keys should be included where appropriate on drawings and in tabular matter.

The use of unit symbols is never mandatory, but when unit symbols are employed they must conform to those given in the Standard.

List of Symbols

Symbols for units are listed alphabetically by name of unit below. The list is intended to be reasonably complete, but could not possibly include all units that might conceivably be used in modern electrical technology. Many compound symbols and many illustrations of the use of the metric prefixes are included. Other combined forms may easily be constructed.

Every effort should be made to maintain the distinction between upper- and lowercase letters shown in the list, wherever the symbols for units are used, even if the surrounding text uses uppercase style.

In the notes accompanying the symbols, some units are identified as SI units. These units belong to the International System of Units (Système International d'Unités), which is the name given in 1960 by the Conférence Générale des Poids et Mesures to the coherent system of units based on the following basic units and quantities:

Unit	Quantity
meter	length
kilogram	mass
second	time

Unit	Quantity
ampere	electric current
kelvin	temperature
candela	luminous intensity

The SI units include as subsystems the MKS system of units, which covers mechanics, and the MKSA or Giorgi system, which covers mechanics, electricity, and magnetism.

Unit	Symbol	Remarks
ampere	A	
ampere-hour	Ah	
ampere-turn	At	
angstrom	Å	
atmosphere		
normal atmosphere	atm	1 atm = 101 325 N/m ²
technical atmosphere	at	1 at = 1 kgf/cm ²
atomic mass unit (unified)	u	The (unified) atomic mass unit is defined as one-twelfth of the mass of an atom of the ¹² C nuclide. Use of the old atomic mass unit (amu), defined by reference to oxygen, is deprecated.
bar	bar	1 bar = 100 000 N/m ²
barn	b	1 b = 10 ⁻²⁸ m ²
bel	B	
billion electronvolts	GeV	The name <i>billion electronvolts</i> is deprecated; see <i>gigaelectronvolt</i> .
British thermal unit	Btu	

LETTER SYMBOLS FOR UNITS USED IN ELECTRICAL SCIENCE AND ELECTRICAL ENGINEERING

Unit	Symbol	Remarks
calorie (International Table calorie)	cal _{IT}	1 cal _{IT} = 4.1868 J The 9th Conférence Générale des Poids et Mesures has adopted the joule as the unit of heat, avoiding the use of the calorie as far as possible
calorie (thermochemical calorie)	cal _{th}	1 cal _{th} = 4.1840 J (See note for International Table calorie.)
candela	cd	The name <i>nit</i> is sometimes used for this unit.
candela per square foot	cd/ft ²	
candela per square meter	cd/m ²	
candle	cd	The unit of luminous intensity has been given the name <i>candela</i> ; use of the name <i>candle</i> for this unit is deprecated.
centimeter	cm	1 cmil = (π/4) · 10 ⁻⁶ in ²
circular mil	cmil	
coulomb	C	
cubic centimeter	cm ³	
cubic foot	ft ³	
cubic foot per minute	ft ³ /min	
cubic foot per second	ft ³ /s	
cubic inch	in ³	
cubic meter	m ³	
cubic meter per second	m ³ /s	
cubic yard	yd ³	
curie	Ci	
cycle per second	c/s	Unit of activity in the field of radiation dosimetry
decibel	dB	The name <i>hertz</i> (Hz) is internationally accepted for this unit.
decibel referred to one milliwatt	dBm	
degree (plane angle)	...°	Note that there is no space between the symbol ° and the letter. The use of the word <i>centigrade</i> for the Celsius temperature scale was abandoned by the Conférence Générale des Poids et Mesures in 1948. In 1967 the CGPM gave the name <i>kelvin</i> to the SI unit of temperature, which was formerly called <i>degree Kelvin</i> , and assigned it the symbol K (without the symbol °).
degree (temperature)	°C	
degree Celsius	°F	
degree Fahrenheit	K	
kelvin		
dyne	dyn	The name <i>lumen per square foot</i> (lm/ft ²) is preferred for this unit.
electronvolt	eV	
erg	erg	
farad	F	
foot	ft	
footcandle	fc	

<i>Unit</i>	<i>Symbol</i>	<i>Remarks</i>
footlambert	fL	If luminance is to be measured in English units, the candela per square foot (cd/ft ²) is preferred.
foot per minute	ft/min	
foot per second	ft/s	
foot per second squared	ft/s ²	
foot poundal	ft · pdl	
foot pound-force	ft · lbf	
gal	Gal	1 Gal = 1 cm/s ²
gallon	gal	The gallon, quart, and pint differ in the U.S. and the U.K. and their use is deprecated.
gallon per minute	gal/min	
gauss	G	The gauss is the electromagnetic CGS unit of magnetic flux density. Use of SI unit, the tesla, is preferred.
gigacycle per second	Gc/s	See note for cycle per second.
gigaelectronvolt	GeV	
gigahertz	GHz	
gilbert	Gb	The gilbert is the electromagnetic CGS unit of magnetomotive force. Use of the SI unit, the ampere (or ampere turn), is preferred.
gram	g	
henry	H	
hertz	Hz	
horsepower	hp	
hour	h	Time may be designated as in the following example: 9 ^h 46 ^m 30 ^s .
inch	in	
inch per second	in/s	
joule	J	
joule per kelvin	J/K	
kelvin	K	In 1967 the CGPM gave the name <i>kelvin</i> to the SI unit of temperature which had formerly been called <i>degree Kelvin</i> and assigned it the symbol K (without the symbol °).
kilocycle per second	kc/s	See note for cycle per second.
kiloelectronvolt	keV	
kilogauss	kG	
kilogram	kg	
kilogram-force	kgf	In some countries the name <i>kilopond</i> (kp) has been adopted for this unit.
kilohertz	kHz	
kilojoule	kJ	
kilohm	kΩ	
kilometer	km	
kilometer per hour	km/h	
kilovar	kvar	

<i>Unit</i>	<i>Symbol</i>	<i>Remarks</i>
kilovolt	kV	
kilovoltampere	kVA	
kilowatt	kW	
kilowatthour	kWh	
knot	knot	
lambert	L	The lambert is the CGS unit of luminance. Use of the SI unit, the candela per square meter, is preferred.
liter	l	
liter per second	l/s	
lumen	lm	
lumen per square foot	lm/ft ²	
lumen per square meter	lm/m ²	
lumen per watt	lm/W	
lumen second	lm · s	
lux	lx	1 lx = 1 lm/m ²
maxwell	Mx	The maxwell is the electromagnetic CGS unit of magnetic flux. Use of the SI unit, the weber, is preferred.
megacycle per second	Mc/s	See note for cycle per second.
megaelectronvolt	MeV	
megahertz	MHz	
megavolt	MV	
megawatt	MW	
megohm	MΩ	
meter	m	
mho	mho	The IEC has adopted the name <i>siemens</i> (S) for this unit.
microampere	μA	
microbar	μbar	
microfarad	μF	
microgram	μg	
microhenry	μH	
micrometer	μm	
micromho	μmho	See note for mho.
micron	μm	The name <i>micrometer</i> is preferred.
microsecond	μs	
microsiemens	μS	
microwatt	μW	
mil	mil	1 mil = 0.001 in
mile (statute)	mi	
nautical mile	nmi	
mile per hour	mi/h	
milliampere	mA	
millibar	mbar	
millibarn	mb	
milligal	mGal	
milligram	mg	
millihenry	mH	

Unit	Symbol	Remarks
milliliter	ml	
millimeter	mm	
conventional millimeter of mercury	mmHg	1 mmHg = 133.322 N/m ²
millimicron	nm	The name <i>nanometer</i> is preferred.
millisecond	ms	
millisiemens	mS	
millivolt	mV	
milliwatt	mW	
minute (plane angle)	...	
minute (time)	min	Time may be designated as in the following example: 9 ^h 46 ^m 30 ^s
nanoampere	nA	
nanofarad	nF	
nanometer	nm	
nanosecond	ns	
nanowatt	nW	
nautical mile	nmi	
neper	Np	
newton	N	
newton meter	N · m	
newton per square meter	N/m ²	
oersted	Oe	The oersted is the electromagnetic CGS unit of magnetic field strength. Use of the SI unit, the ampere per meter, is preferred.
ohm	Ω	
ounce (avoirdupois)	oz	
picoampere	pA	
picofarad	pF	
picosecond	ps	
picowatt	pW	
pint	pt	The gallon, quart, and pint differ in the U.S. and the U.K., and their use is deprecated.
pound	lb	
poundal	pd	
pound-force	lbf	
pound-force foot	lbf · ft	
pound-force per square inch	lbf/in ²	
pound per square inch		Although use of the abbreviation psi is common, it is not recommended. See pound-force per square inch.
quart	qt	The gallon, quart, and pint differ in the U.S. and the U.K., and their use is deprecated.
rad	rd	Unit of absorbed dose in the field of radiation dosimetry.
radian	rad	
rem	rem	Unit of dose equivalent in the field of radiation dosimetry.

<i>Unit</i>	<i>Symbol</i>	<i>Remarks</i>
revolution per minute	r/min	Although use of the abbreviation rpm is common, it is not recommended.
revolution per second	r/s	
roentgen	R	Unit of exposure in the field of radiation dosimetry.
second (plane angle)	...''	
second (time)	s	Time may be designated as in the following example: $9^h 46^m 30^s$.
siemens	S	$1\text{ S} = 1\ \Omega^{-1}$
square foot	ft ²	
square inch	in ²	
square meter	m ²	
square yard	yd ²	
steradian	sr	
tesla	T	$1\text{ T} = 1\text{ Wb/m}^2$
tonne	t	$1\text{ t} = 1000\text{ kg}$
(unified) atomic mass unit	u	The (unified) atomic mass unit is defined as one-twelfth of the mass of an atom of the ¹² C nuclide. Use of the old atomic mass unit (amu), defined by reference to oxygen, is deprecated.
var	var	Unit of reactive power
volt	V	
voltampere	VA	Unit of apparent power
watt	W	
watthour	Wh	
watt per steradian	W/sr	
watt per steradian square meter	W/sr · m ²)	
weber	Wb	$1\text{ Wb} = 1\text{ V} \cdot \text{s}$
yard	yd	

CONVERSION OF ELECTROMAGNETIC UNITS

Three common systems of electromagnetic units are in universal employ. They are:

1. The absolute system of CGS electromagnetic system.
2. The practical CGS electromagnetic system.
3. The MKS system (Gaussian or Giorgi depending upon the choice of constants).

The chart allows rapid conversion from one system to another. In any one row, any quantity divided by any other quantity produces unity.

These Quantities Are Those Effected by Rationalization

Quantity	Rationalized			Unrationalized		
	MKS	CGS EM	CGS ES	MKS	CGS EM	CGS ES
Dielectric displacement	1	10^{-5}	3×10^5	4π	$4\pi \times 10^{-5}$	$12\pi \times 10^5$
	10^5	1	3×10^{10}	$4\pi \times 10^5$	4π	$12\pi \times 10^{10}$
	$1/3 \times 10^{-5}$	$1/3 \times 10^{-10}$	1	$4\pi/3 \times 10^{-5}$	$4\pi/3 \times 10^{-10}$	4π
	$1/4\pi$	$1/4\pi \times 10^{-5}$	$3/4\pi \times 10^5$	1	10^{-5}	3×10^{-5}
	$1/4\pi \times 10^5$	$1/4\pi$	$3/4\pi \times 10^{10}$	10^5	1	3×10^{10}
	$1/12\pi \times 10^{-5}$	$1/12\pi \times 10^{-10}$	$1/4\pi$	$1/3 \times 10^{-5}$	$1/3 \times 10^{-10}$	1
Units	Coulomb/m ²	Abcoulomb/m ²	Statcoulomb/cm ²	Coulomb/m ²	Abcoulomb/cm ²	Statcoulomb/cm ²
Magnetic field intensity	1	10^{-3}	3×10^7	4π	$4\pi \times 10^{-3}$	$12\pi \times 10^7$
	10^3	1	3×10^{10}	$4\pi \times 10^3$	4π	$12\pi \times 10^{10}$
	$1/3 \times 10^{-7}$	$1/3 \times 10^{-10}$	1	$4\pi/3 \times 10^{-7}$	$4\pi/3 \times 10^{-10}$	4π
	$1/4\pi$	$1/4\pi \times 10^{-3}$	$3/4\pi \times 10^7$	1	10^{-3}	3×10^7
	$1/4\pi \times 10^3$	$1/4\pi$	$3/4\pi \times 10^{10}$	10^3	1	3×10^{10}
	$1/12\pi \times 10^{-7}$	$1/12\pi \times 10^{-10}$	$1/4\pi$	$1/3 \times 10^{-7}$	$1/3 \times 10^{-10}$	1
Units	Amp-turn/m	Oersted	ESU	Amp-turn/m	Oersted	ESU
Magnetomotive force	1	10^{-1}	3×10^9	4π	$4\pi \times 10^{-1}$	$12\pi \times 10^9$
	10	1	3×10^{10}	40π	4π	$12\pi \times 10^{10}$
	$1/3 \times 10^{-9}$	$1/3 \times 10^{-10}$	1	$4\pi/3 \times 10^{-9}$	$4\pi/3 \times 10^{-10}$	4π
	$1/4\pi$	$1/4\pi \times 10^{-1}$	$3/4\pi \times 10^9$	1	10^{-1}	3×10^9
	$10/4\pi$	$1/4\pi$	$3/4\pi \times 10^{10}$	10	1	3×10^{10}
	$1/12\pi \times 10^{-9}$	$1/12\pi \times 10^{-10}$	$1/4\pi$	$1/3 \times 10^{-9}$	$1/3 \times 10^{-10}$	1
Units	Amp-turn	Gilbert	ESU	Amp-turn	Gilbert	ESU

Quantity	Practical Unit	Electromagnetic Unit	Electrostatic Unit
	MKS	CGS EM	CGS ES
1. Capacitance	1 Farad	10^{-9} Abfarad	9×10^{11} Statfarad
	10^9 Farad	1 Abfarad	9×10^{20} Statfarad
	$1/9 \times 10^{-11}$ Farad	$1/9 \times 10^{-20}$ Abfarad	1 Statfarad
2. Charge	1 Coulomb	10^{-1} Abcoulomb	3×10^9 Statcoulomb
	10 Coulomb	1 Abcoulomb	3×10^{10} Statcoulomb
	$1/3 \times 10^{-9}$ Coulomb	$1/3 \times 10^{-10}$ Abcoulomb	1 Statcoulomb
3. Charge density	1 Coulomb/m ²	10^{-7} Abcoulomb/cm ²	3×10^2 Statcoulomb/cm ²
	10^7 Coulomb/m ²	1 Abcoulomb/cm ²	3×10^{10} Statcoulomb/cm ²
	$1/3 \times 10^{-3}$ Coulomb/m ²	$1/3 \times 10^{-10}$ Abcoulomb/cm ²	1 Statcoulomb/cm ²
4. Conductivity	1 Mho/m	10^{-11} Abmho/cm	9×10^9 Statmho/cm
	10^{11} Mho/m	1 Abmho/cm	9×10^{20} Statmho/cm
	$1/9 \times 10^{-9}$ Mho/m	$1/9 \times 10^{-20}$ Abmho/cm	1 Statmho/cm
5. Current	1 Ampere	10^{-1} Abampere	3×10^9 Statampere
	10 Ampere	1 Abampere	3×10^{10} Statampere
	$1/3 \times 10^{-9}$ Ampere	$1/3 \times 10^{-10}$ Abampere	1 Statampere
6. Current density	1 Ampere/m ²	10^{-5} Abampere/cm ²	3×10^5 Statampere/cm ²
	10^5 Ampere/m ²	1 Abampere/cm ²	3×10^{10} Statampere/cm ²
	$1/3 \times 10^{-5}$ Ampere/m ²	$1/3 \times 10^{-10}$ Abampere/cm ²	1 Statampere/cm ²
7. Electric field intensity	1 Volt/meter	10^6 Abvolt/cm	$1/3 \times 10^{-4}$ Statvolt/cm
	10^{-6} Volt/meter	1 Abvolt/cm	$1/3 \times 10^{-10}$ Statvolt/cm
	3×10^9 Volt/meter	3×10^{10} Abvolt/cm	1 Statvolt/cm
8. Electric potential	1 Volt	10^6 Abvolts	$1/3 \times 10^{-2}$ Statvolts
	10^{-6} Volt	1 Abvolt	$1/3 \times 10^{-10}$ Statvolts
	3×10^2 Volt	3×10^{10} Abvolts	1 Statvolt
9. Electric dipole moment	1 Coulomb-meter	10 Abcoulomb-cm	3×10^{11} Statcoulomb-cm
	10^{-1} Coulomb-meter	1 Abcoulomb-cm	3×10^{10} Statcoulomb-cm
	$1/3 \times 10^{-11}$ Coulomb-meter	$1/3 \times 10^{-10}$ Abcoulomb-cm	1 Statcoulomb-cm
10. Energy	1 Joule	10^7 Erg	10^7 Erg
	10^{-7} Joule	1 Erg	1 Erg
	10^{-7} Joule	1 Erg	1 Erg
11. Force	1 Newton	10^5 Dyne	10^5 Dyne
	10^{-5} Newton	1 Dyne	1 Dyne
	10^{-5} Newton	1 Dyne	1 Dyne
12. Flux density	1 Weber/m ²	10^4 Gauss	$1/3 \times 10^{-6}$ esu
	10^{-4} Weber/m ²	1 Gauss	$1/3 \times 10^{-10}$ esu
	3×10^6 Weber/m ²	3×10^{10} Gauss	1 esu
13. Inductance	1 Henry	10^9 Abhenry	$1/9 \times 10^{-11}$ Stathenry
	10^{-9} Henry	1 Abhenry	$1/9 \times 10^{-20}$ Stathenry
	9×10^{11} Henry	9×10^{20} Abhenry	1 Stathenry
14. Inductive capacity	1 Farad/meter	10^{-11} Abfarad/cm	9×10^9 Statfarad/cm
	10^{11} Farad/meter	1 Abfarad/cm	9×10^{20} Statfarad/cm
	$1/9 \times 10^{-9}$ Farad/meter	$1/9 \times 10^{-20}$ Abfarad/cm	1 Statfarad/cm
15. Magnetic flux	1 Weber	10^8 Maxwell	$1/3 \times 10^{-2}$ esu
	10^{-8} Weber	1 Maxwell	$1/3 \times 10^{-10}$ esu
	3×10^2 Weber	3×10^{10} Maxwell	1 esu
16. Magnetic dipole moment	1 Ampere-meter ²	10^3 Abamp-cm ²	3×10^{13} Statamp-cm ²
	10^{-3} Ampere-meter ²	1 Abamp-cm ²	3×10^{10} Statamp-cm ²
	$1/3 \times 10^{-13}$ Ampere-meter ²	$1/3 \times 10^{-10}$ Abamp-cm ²	1 Statamp-cm ²
17. Permeability	1 Henry meter	10^9 Abhenry cm	$1/9 \times 10^{-13}$ Stathenry cm
	10^{-7} Henry meter	1 Abhenry cm	$1/9 \times 10^{-20}$ Stathenry cm
	9×10^{13} Henry meter	9×10^{20} Abhenry cm	1 Stathenry cm
18. Power	1 Watt	10^7 erg/sec	10^7 erg/sec
	10^{-7} Watt	1 erg/sec	1 erg/sec
	10^{-7} Watt	1 erg/sec	1 erg/sec
19. Resistance	1 Ohm	10^9 Abohm	$1/9 \times 10^{-13}$ Statohm
	10^{-9} Ohm	1 Abohm	$1/9 \times 10^{-20}$ Statohm
	9×10^{11} Ohm	9×10^{20} Abohm	1 Statohm

SPACE-TIME-VELOCITY AND ACCELERATION FORMULAS

This tabulation presents all basic linear motion formulas with all their variations. Terms are defined and units of measurement are specified.

- A = Acceleration or deceleration—ft/sec/sec (32.2 for gravity)
 D = Distance—ft (may be used in lieu of "H" in vertical free fall)
 E = Energy—ft—lbs
 F = Force—lbs
 H = Height—ft (may be used lieu of "D" with A—32.2)

$$M = \text{Mass} \quad \frac{W}{32.2} = \frac{\text{lb—sec}^2}{\text{ft}}$$

T = Time—sec

V_a = Average velocity—ft/sec

V_f = Final velocity—ft/sec

V_i = Initial velocity—ft/sec

W = Weight—lbs

To Find	Formulae					
A	$\frac{V_f - V_i}{T}$	$\left(\text{When } V_i = 0\right) \frac{V_f}{T}$	$\left(\text{When } V_i = 0\right) \frac{V_f^2}{2D}$	$\frac{2D}{T^2}$	$\frac{WV_a}{FT}$	$\frac{F}{M}$
D	$V_a T$	$\frac{T(V_i + V_f)}{2}$	$\left(\text{When } V_i = 0\right) \frac{V_f T}{2}$	$\frac{V_a^2}{2A}$	$\frac{AT^2}{2}$	$\frac{E}{F}$
E	FD	WH				
F	MA	$\frac{M(V_f - V_i)}{T}$	$\frac{E}{D}$	$\frac{WV_a}{AT}$		
H	$\frac{E}{W}$	$16.1 T^2$				
M	$\frac{W}{32.2}$	$\frac{F}{A}$	$\frac{FT}{V_f - V_i}$			
T	$\frac{D}{V_a}$	$\frac{2D}{V_f + V_i}$	$\frac{V_f - V_i}{A}$	$\left(\text{When } V_i = 0\right) \frac{V_f}{A}$	$\left(\text{When } V = 0\right) \frac{2D}{V_f}$	
	$\sqrt{\frac{2D}{A}}$	$\sqrt{\frac{H}{4}}$	$\frac{WV_a}{FA}$	$\frac{M(V_f - V_i)}{F}$		
V _f	$2V_a - V_i$	$\left(\text{When } V_i = 0\right) 2V_a$	$\frac{2D}{T} - V_i$	$\left(\text{When } V_i = 0\right) \frac{2D}{T}$	$AT + V_i$	$\left(\text{When } V_i = 0\right) AT$
V _i	$2V_a - V_f$	$\frac{2D}{T} - V_f$	$V_f - AT$	$V_f - \frac{FT}{M}$		
W	$\frac{AFT}{V_a}$	$32.2 M$	$\frac{E}{H}$			

CONVERSION FACTORS

To Convert	Into	Multiply By	To Convert	Into	Multiply By
A					
Abcoulomb	Statcoulombs	2.998×10^{10}	ares	sq meters	100.0
Acre	Sq. chain (Gunters)	10	Astronomical Unit	Kilometers	1.495×10^8
Acre	Rods	160	Atmospheres	Ton/sq. inch	.007348
Acre	Square links (Gunters)	1×10^5	atmospheres	cms of mercury	76.0
Acre	Hectare or sq. hectometer	.4047	atmospheres	ft. of water (at 4°C)	33.90
acres	sq feet	43,560.0	atmospheres	in. of mercury (at 0°C)	29.92
acres	sq meters	4,047.	atmospheres	kgs/sq cm	1.0333
acres	sq miles	1.562×10^{-3}	atmospheres	kgs/sq meter	10,332.
acres	sq yards	4,840.	atmospheres	pounds/sq.in.	14.70
acres	cu feet	43,560.0	atmospheres	tons/sq ft	1.058
acre-feet	gallons	3.259×10^5	B		
amperes/sq cm	amps/sq in.	6.452	cu. inches	quarts (dry)	7056.
amperes/sq cm	amps/sq meter	10^4	quarts (dry)	gallons	105.0
amperes/sq in.	amps/sq cm	0.1550	gallons (oil)	gallons (oil)	31.5
amperes/sq meter	amps/sq cm	$1,550.0$	bars	atmospheres	42.0
amperes/sq meter	amps/sq in.	10^{-4}	bars	dynes/sq cm	0.9869
ampere-hours	coulombs	$3,600.0$	bars	kg/sq meter	10^6
ampere-hours	faradays	0.03731	bars	pounds/sq ft	$1,020 \times 10^4$
ampere-turns	gilberts	1.257	bars	pounds/sq in.	2,089.
ampere-turns/cm	amp-turns/in.	2.540	Beryll	Dyne/sq. cm.	14.50
ampere-turns/cm	amp-turns/meter	100.0	Bolt (US Cloth)	Meters	1,000
ampere-turns/cm	gilberts/cm	1.257	BTU	Liter-Atmosphere	36.576
ampere-turns/in.	amp-turns/cm	0.3937	Btu	ergs	10,409
ampere-turns/in.	amp-turns/meter	39.37	Btu	foot-lbs	1.0550×10^{10}
ampere-turns/in.	gilberts/cm	0.4950	Btu	gram-calories	778.3
ampere-turns/meter	amp-turns/cm	0.01	Btu	horsepower-hrs	252.0
ampere-turns/meter	amp-turns/in.	0.0254	Btu	joules	$3,931 \times 10^{-4}$
ampere-turns/meter	gilberts/cm	0.01257	Btu	kilogram-calories	1,054.8
Angstrom unit	Inch	3937×10^{-9}	Btu	kilogram-meters	0.2520
Angstrom unit	Meter	1×10^{-10}	Btu/hr	kilowatt-hrs	107.5
Angstrom unit	Micron or (Mu)	1×10^{-4}	Btu/hr	foot-pound/sec	$2,928 \times 10^{-4}$
Are	Acre (US)	.02471	Btu/hr	gram-cal/sec	0.2162
ares	sq. yards	119.60	Btu/hr	horsepower-hrs	0.7000
ares	ecres	0.02471	Btu/hr	watts	$3,929 \times 10^{-4}$
					0.2931

To Convert	Into	Multiply By	To Convert	Into	Multiply By
8tu/min	foot-lbs/sec	12.96	cubic centimeters	gallons (U.S. liq.)	2.642×10^{-4}
8tu/min	horsepower	0.02356	cubic centimeters	liters	0.001
8tu/min	kilowatts	0.01757	cubic centimeters	pints (U.S. liq.)	2.113×10^{-3}
8tu/min	watts	17.57	cubic centimeters	quarts (U.S. liq.)	1.057×10^{-3}
8tu/sq ft/min	watts/sq in.	0.1221	cubic foot	bushels (dry)	0.8036
Bucket (8r. dry)	Cubic Cm.	1.818×10^4	cubic foot	cu cms	28,320.0
bushels	cu ft	1.2445	cubic foot	cu inches	1,728.0
bushels	cu in.	2,150.4	cubic foot	cu meters	0.02832
bushels	cu meters	0.03524	cubic foot	cu yards	0.3704
bushels	liters	35.24	cubic foot	gallons (U.S. liq.)	7.48052
bushels	pecks	4.0	cubic foot	liters	28.32
bushels	pints (dry)	64.0	cubic foot	pints (U.S. liq.)	59.84
bushels	quarts (dry)	32.0	cubic foot	quarts (U.S. liq.)	29.92
			cubic foot/min	cu cms/sec	472.0
			cubic foot/min	gallons/sec	0.1247
			cubic foot/min	liters/sec	0.4720
			cubic foot/min	pounds of water/min	62.43
			cubic foot/sec	million gals/day	0.646317
			cubic foot/sec	gallons/min	448.831
			cubic inches	cu cms	16.39
			cubic inches	cu feet	5.787×10^{-4}
			cubic inches	cu meters	1.639×10^{-5}
			cubic inches	cu yards	2.143×10^{-5}
			cubic inches	gallons (U.S. liquid)	4.329×10^{-3}
			cubic inches	liters	0.01639
			cubic inches	mil-foot	1.061×10^5
			cubic inches	pints (U.S. liq.)	0.03463
			cubic inches	quarts (U.S. liq.)	0.01732
			cubic meters	bushels (dry)	28.38
			cubic meters	cu cms	10^6
			cubic meters	cu feet	35.31
			cubic meters	cu inches	61,023.0
			cubic meters	cu yards	1.308
			cubic meters	gallons (U.S. liq.)	264.2
			cubic meters	liters	1,000.0
			cubic meters	pints (U.S. liq.)	2,113.0

C

Calories, gram (mean)	B.T.U. (mean)	3.9685×10^{-3}
centares (centares)	sq meters	1.0
Centigrade (Celsius)	Fahrenheit	$(C^\circ \times 9/5) + 32$
Centigrams	grams	0.01
Centiliter	Ounce fluid (US)	.3382
Centiliter	Cubic inch	.6103
Centiliter	drams	2.705
centiliters	liters	0.01
centimeters	feet	3.281×10^{-2}
centimeters	inches	0.3937
centimeters	kilometers	10^{-5}
centimeters	meters	0.01
centimeters	miles	6.214×10^{-6}
centimeters	millimeters	10.0
centimeters	mils	393.7
centimeters	yards	1.094×10^{-2}
centimeter-dynes	cm-grams	1.020×10^{-3}
centimeter-dynes	meter-kgs.	1.020×10^{-8}
centimeter-dynes	pound-feet	7.376×10^{-8}
centimeter-grams	cm-dynes	980.7
centimeter-grams	meter-kgs	10^{-5}

[illegible]

	F		
ferads		microferads	
feradays/sec		Ampere (absolute)	10^6
feradays		ampere-hours	9.6500×10^4
feradays		coulombs	26.80
Fathom		Meter	9.649×10^4
fathoms		foot	1.828804
feet		centimeters	6.0
feet		feet	30.48
feet		kilometers	3.048×10^{-4}
feet		meters	0.3048
feet		miles (naut.)	1.645×10^{-4}
feet		miles (stat.)	1.894×10^{-4}
feet		millimeters	304.8
feet		mils	1.2×10^4
feet of water		atmospheres	0.02950
feet of water		in. of mercury	0.8826
feet of water		kgs/sq cm	0.03048
feet of water		kgs/sq meter	304.8
feet of water		pounds/sq ft	62.43
feet of water		pounds/sq in.	0.4335
feet/min		cm/sec	0.5080
feet/min		feet/sec	0.01667
feet/min		km/hr	0.01829
feet/min		meters/min	0.3048
feet/min		miles/hr	0.01136
feet/sec		cm/sec	30.48
feet/sec		km/hr	1.097
feet/sec		knots	0.5921
feet/sec		meters/min	18.29
feet/sec		miles/hr	0.6818
feet/sec		mm/min	0.01136
feet/sec		cm/sec/sec	30.48
feet/sec/sec		km/hr/sec	1.097
feet/sec/sec		meters/sec/sec	0.3048
feet/sec/sec		miles/hr/sec	0.6818
feet/100 feet		per cent grade	1.0
foot-candle		lumen/sq., meter	10.764
foot-pounds		Btu	1.286×10^{-3}
		gausses	
		gausses	6.452×10^{-8}
		gilberts	10^{-4}
		gilberts/cm	0.7958
		gilberts/cm	0.7958
		gilberts/in	2.021
		emp-turns/meter	79.58
		cubic cm.	142.07
		liters	0.1183
		pints (liq.)	0.25
		Radian	0.1571
		drams (avoirdupois)	0.03657143
		grains (avdp)	1.0
		grains	0.06480
		ounces (avdp)	2.0833×10^{-3}
		pennyweight (troy)	0.04167
		parts/million	17.118
		pound/million gal	142.86
		parts/million	14.286
		dynes	980.7
		grains	15.43
		joules/cm	9.807×10^{-5}
		joules/meter (newtons)	9.807×10^{-3}
		kilograms	0.001
		milligrams	1.000
		ounces (avdp)	0.03527
		ounces (troy)	0.03215
		poundals	0.07093
		pounds	2.205×10^{-3}
		pounds/inch	5.600×10^{-3}
		pounds/cu ft	62.43
		pounds/cu in	0.03613
		pounds/mil-foot	3.405×10^{-7}
		grains/gal	58.417
		pounds/1,000 gal	8.345
		pounds/cu ft	0.062427
		parts/million	1,000.0
		parts/million	2.0481
		pounds/sq ft	3.9863×10^{-3}
		Btu	4.1868×10^7
		ergs	

To Convert	Into	Multiply By	To Convert	Into	Multiply By
gram-calories	foot-pounds	3.0880	joules	8tu	9.480×10^{-4}
gram-calories	horsepower-hrs	1.5596×10^{-6}	joules	ergs	10^7
gram-calories	kilowatt-hrs	1.1630×10^{-6}	joules	foot-pounds	0.7376
gram-calories	watt-hrs	1.1630×10^{-3}	joules	kg-calories	2.389×10^{-4}
gram-calories/sec	Btu/hr	14.286	joules	kg-meters	0.1020
gram-centimeters	8tu	9.297×10^{-8}	joules	watt-hrs	2.778×10^{-4}
gram-centimeters	ergs	980.7	joules/cm	grams	1.020×10^4
gram-centimeters	joules	9.807×10^{-5}	joules/cm	dynes	10^7
gram-centimeters	kg-cal	2.343×10^{-8}	joules/cm	joules/meter (newtons)	100.0
gram-centimeters	kg-meters	10^{-5}	joules/cm	poundals	723.3
	H		joules/cm	pounds	22.48
Hand	Cm.	10.16		K	
hectares	acres	2.471	kilograms	dynes	980,665.
hectograms	sq feet	1.076×10^5	kilograms	grams	1,000.0
hectoliters	grams	100.0	kilograms	joules/cm	0.09807
hectoliters	liters	100.0	kilograms	joules/meter (newtons)	9.807
hectometers	meters	100.0	kilograms	poundals	70.93
hectowatts	watts	100.0	kilograms	tons (long)	2.205
henries	millihenries	1,000.0	kilograms	tons (short)	1.102×10^{-3}
Hogheads (British)	cubic ft.	10.114	kilograms/cu meter	grams/cu cm	0.001
Hogheads (U.S.)	cubic ft.	8.42184	kilograms/cu meter	pounds/cu ft	0.06243
Hogheads (U.S.)	gallons (U.S.)	63	kilograms/cu meter	pounds/cu in.	3.613×10^{-5}
horsepower	Btu/min	42.44	kilograms/cu meter	pounds/mil-foot	3.405×10^{-10}
horsepower	foot-lb/min	33,000.	kilograms/meter	pounds/ft	0.6720
horsepower	foot-lb/sec	550.0	Kilogram/sq. cm.	Dynes	980,665
horsepower (metric)	horsepower	0.9863	kilograms/sq cm	atmospheres	0.9678
(542.5 ft lb/sec)	(550 ft lb/sec)		kilograms/sq cm	feet of water	32.81
horsepower	horsepower (metric)	1.014	kilograms/sq cm	inches of mercury	28.96
(550 ft lb/sec)	(542.5 ft lb/sec)		kilograms/sq cm	pounds/sq ft	14.22
horsepower	kg-calories/min	10.68	kilograms/sq cm	pounds/sq in.	9.678×10^{-5}
horsepower	watts	0.7457	kilograms/sq cm	atmospheres	98.07×10^{-6}
horsepower	8tu/hr	33.479	kilograms/sq meter	bars	3.281×10^{-3}
horsepower (boiler)	kilowatts	9.803	kilograms/sq meter	feet of water	2.896×10^{-3}
horsepower (boiler)	8tu	2.547	kilograms/sq meter	inches of mercury	
horsepower-hrs	ergs	2.6845×10^{13}	kilograms/sq meter		

horsepower-hrs	foot-lbs	1.98×10^6	kilograms/sq meter	pounds/sq ft	0.2048
horsepower-hrs	gram-calories	641,190	kilograms/sq meter	pounds/sq in.	1.422×10^{-3}
horsepower-hrs	joules	2.684×10^6	kilograms/sq mm	kg/sq meter	10^6
horsepower-hrs	kg-calories	641.1	kilogram-calories	Btu	3.968
horsepower-hrs	kg-meters	2.737×10^5	kilogram-calories	foot-pounds	3.088
horsepower-hrs	kwatt-hrs	0.7457	kilogram-calories	hp-hrs	1.560×10^{-3}
hours	days	4.167×10^{-2}	kilogram-calories	joules	4,186
hours	weeks	5.952×10^{-3}	kilogram-calories	kg-meters	426.9
Hundredweights (long)	pounds	112	kilogram-calories	kilojoules	4186
Hundredweights (long)	tons (long)	0.05	kilogram-calories	kilowatt-hrs	1.163×10^{-3}
Hundredweights (short)	ounces (avoirdupois)	1600	kilogram-calories	Btu	9.294×10^{-3}
Hundredweights (short)	pounds	100	kilogram meters	ergs	9.804×10^7
Hundredweights (short)	tons (metric)	0.0453592	kilogram meters	foot-pounds	7.233
Hundredweights (short)	tons (long)	0.0446429	kilogram meters	joules	9.804
			kilogram meters	kg-calories	2.342×10^{-3}
			kilogram meters	kilowatt-hrs	2.723×10^{-6}
			kilolines	maxwells	1,000.0
inches	centimeters	2.540	kiloliters	liters	1,000.0
inches	meters	2.540×10^{-2}	kilometers	centimeters	10^5
inches	miles	1.578×10^{-5}	kilometers	feet	3.281
inches	millimeters	25.40	kilometers	inches	3.937×10^4
inches	mils	1,000.0	kilometers	meters	1,000.0
inches	yards	2.778×10^{-2}	kilometers	miles	0.6214
inches of mercury	atmospheres	0.03342	kilometers	millimeters	10^6
inches of mercury	feet of water	1.133	kilometers	yards	1.094
inches of mercury	kg/sq cm	0.03453	kilometers/hr	cms/sec	27.78
inches of mercury	kg/sq meter	345.3	kilometers/hr	feet/min	54.68
inches of mercury	pounds/sq ft	70.73	kilometers/hr	feet/sec	0.9113
inches of mercury	pounds/sq in.	0.4912	kilometers/hr	knots	0.5396
inches of water (at 4°C)	atmospheres	2.458×10^{-3}	kilometers/hr	meters/min	16.67
inches of water (at 4°C)	inches of mercury	0.07355	kilometers/hr	miles/hr	0.6214
inches of water (at 4°C)	kg/sq cm	2.540×10^{-3}	kilometers/hr/sec	cm/sec/sec	27.78
inches of water (at 4°C)	ounces/sq in.	0.5781	kilometers/hr/sec	ft/sec/sec	0.9113
inches of water (at 4°C)	pounds/sq ft	5.204	kilometers/hr/sec	meters/sec/sec	0.2778
inches of water (at 4°C)	pounds/sq in.	0.03613	kilometers/hr/sec	miles/hr/sec	0.6214
International Ampere	Ampere (absolute)	.9998	kilowatts	Btu/min	56.92
International Volt	Volts (absolute)	1.0003	kilowatts	foot-lbs/min	4.426×10^4
International volt	Joules (absolute)	1.593×10^{-19}	kilowatts	foot-lbs/sec	737.6
International volt	Joules	9.654×10^4	kilowatts	horsepower	1.341

<i>To Convert</i>	<i>Into</i>	<i>Multiply By</i>	<i>To Convert</i>	<i>Into</i>	<i>Multiply By</i>
kilowatts	kg-calories/min	14.34	meters/sec	miles/hr	2.237
kilowatts	watts	1,000.0	meters/sec	miles/min	0.03728
kilowatt-hrs	Btu	3,413.	meters/sec/sec	cms/sec/sec	100.0
kilowatt-hrs	ergs	3.600×10^{13}	meters/sec/sec	ft/sec/sec	3.281
kilowatt-hrs	foot-lbs	2.655×10^6	meters/sec/sec	kms/hr/sec	3.6
kilowatt-hrs	gram-calories	859,850.	meters/sec/sec	miles/hr/sec	2.237
kilowatt-hrs	horsepower-hrs	1.341	meter-kilograms	cm-dynes	9.807×10^7
kilowatt-hrs	joules	3.6×10^6	microfarad	farads	10^{-6}
kilowatt-hrs	kg-calories	859,850	micrograms	grams	10^{-6}
kilowatt-hrs	kg-meters	3.671×10^5	microhms	megohms	10^{-12}
	pounds of water evaporated from and at 212° F.	3.53	microhms	ohms	10^{-6}
	pounds of water raised from 62° to 212° F.	22.75	microliters	liters	1×10^{-6}
	feet/hr	6,080.	microns	meters	6,080.27
knots	kilometers/hr	1.8532	miles (naut.)	kilometers	1.853
knots	nautical miles/hr	1.0	miles (naut.)	meters	1,853.
knots	statute miles/hr	1.151	miles (statute)	miles (statute)	1.1516
knots	yards/hr	2,027.	miles (naut.)	yards	2,027.
knots	feet/sec	1.689	miles (statute)	centimeters	1.609×10^5
	L		miles (statute)	feet	5,280.
league	miles (approx.)	3.0	miles (statute)	inches	6.336×10^4
Light year	Miles	5.9×10^{12}	miles (statute)	kilometers	1,609.
Light year	Kilometers	9.46091×10^{12}	miles (statute)	meters	1,609.
lines/sq cm	gausses	1.0	miles (statute)	miles (naut.)	0.8684
lines/sq in.	gausses	0.1550	miles (statute)	yards	1,760.
lines/sq cm	webers/sq cm	1.550×10^{-9}	miles (statute)	cms/sec	44.70
lines/sq in.	webers/sq in.	10^{-6}	miles/hr	feet/min	88.
lines/sq in.	webers/sq meter	1.550×10^{-5}	miles/hr	feet/sec	1.467
links (engineer's)	inches	12.0	miles/hr	kms/hr	1.609
links (surveyor's)	inches	7.92	miles/hr	kms/min	0.02682
liters	bushels (U.S. dry)	0.02838	miles/hr	knots	0.8684
liters	cu cm	1,000.0	miles/hr	meters/min	26.82
liters	cu foot	0.03531	miles/hr	miles/min	0.1667
liters	cu inches	61.02	miles/hr/sec	cms/sec	44.70
			miles/hr/sec	feet/sec/sec	1.467

liters	cu meters	0.001	miles/hr/sec	kms/hr/sec	1.609
liters	cu yards	1.308×10^{-3}	miles/hr/sec	meters/sec/sec	0.4470
liters	gallons (U.S. liq.)	0.2642	miles/min	cms/sec	2,682
liters	pints (U.S. liq.)	2.113	miles/min	feet/sec	88
liters	quarts (U.S. liq.)	1.057	miles/min	kms/min	1.609
liters/min	cu ft/sec	5.886×10^{-4}	miles/min	knots/min	0.8684
liters/min	gals/sec	4.403×10^{-3}	miles/min	miles/hr	60.0
lumens/sq ft	foot-candles	1.0	mil-feet	cu inches	9.425×10^{-6}
Lumen	Spherical candle power	.07958	milliers	kilograms	1,000.
Lumen	Watt	.001496	Millimicrons	meters	1×10^{-9}
Lumen/sq. meter	Lumen/sq. meter	10.76	Milligrams	grains	0.01543236
lux	foot-candles	0.0929	milligrams	grams	0.001
			millihenries	henries	1.0
	M		milliliters	liters	0.001
maxwells	kilolines	0.001	millimeters	centimeters	0.1
maxwells	webbers	10^{-8}	millimeters	feet	3.281×10^{-3}
maxwells	maxwells	10^6	millimeters	inches	0.03937
megohms	microhms	10^{12}	millimeters	kilometers	10^{-6}
megohms	ohms	10^6	millimeters	meters	0.001
meters	centimeters	100.0	millimeters	milas	6.214×10^{-7}
meters	feet	3.281	millimeters	mls	39.37
meters	inches	39.37	millimeters	yards	1.094×10^{-3}
meters	kilometers	0.001	millimeters	cu ft/sec	1.54723
meters	miles (naut.)	5.396×10^{-4}	million gals/day	centimeters	2.540×10^{-3}
meters	miles (stat.)	6.214×10^{-4}	mls	feet	8.333×10^{-5}
meters	millimeters	1,000.0	mls	inches	0.001
meters	yards	1.094	mls	kilometers	2.540×10^{-8}
meters	varas	1.179	mls	yards	2.778×10^{-5}
meters/min	cms/sec	1.667	miner's inches	cu ft/min	1.5
meters/min	feet/min	3.281	Minims (British)	cubic cm.	0.059192
meters/min	feet/sec	0.05468	Minims (U.S., fluid)	cubic cm.	0.061612
meters/min	kms/hr	0.06	Minutes (angles)	degrees	0.01667
meters/min	knots	0.03238	minutes (angles)	quadrants	1.852×10^{-4}
meters/min	miles/hr	0.03728	minutes (angles)	radians	2.909×10^{-4}
meters/sec	feet/min	196.8	minutes (angles)	seconds	60.0
meters/sec	feet/sec	3.281	myriagrams	kilograms	10.0
meters/sec	kilometers/hr	3.6	myriawatts	kilometers	10.0
meters/sec	kilometers/min	0.06		kilowatts	10.0

To Convert	Into	N	Multiply By
nepers	decibels		8.686
Newton	Dynes		1×10^5
O			
OHM (International)	OHM (absolute)		1.0005
ohms	megohms		10^{-6}
ohms	microhms		10^6
ounces	drams		16.0
ounces	grains		437.5
ounces	grams		28.349527
ounces	pounds		0.0625
ounces	ounces (troy)		0.9115
ounces	tons (long)		2.790×10^{-7}
ounces	tons (metric)		2.835×10^{-7}
ounces (fluid)	cu inches		1.805
ounces (fluid)	liters		0.02957
ounces (troy)	grains		480.0
ounces (troy)	grams		31.103481
ounces (troy)	ounces (avdp.)		1.09714
ounces (troy)	pennyweights (troy)		20.0
ounces (troy)	pounds (troy)		0.08333
ounces/sq. inch	Dynes/sq. cm.		4.309
ounces/sq in.	pounds/sq in.		0.0625
P			
Parsec	Miles		19×10^{12}
Parsec	Kilometers		3.084×10^{13}
parts/million	grains/U.S. gal		0.0584
parts/million	grains/imp. gal		0.07016
parts/million	pounds/million gal		8.345
Packs (British)	cubic inches		554.6
Packs (British)	liters		9.091901
Packs (U.S.)	bushels		0.25
Packs (U.S.)	cubic inches		537.605
Packs (U.S.)	liters		8.809582

To Convert	Into	Multiply By
pounds (troy)	pennyweights (troy)	240.0
pounds (troy)	pounds (avdp.)	0.822857
pounds (troy)	tons (long)	3.6735×10^{-4}
pounds (troy)	tons (metric)	3.7324×10^{-4}
pounds (troy)	tons (short)	4.1143×10^{-4}
pounds of water	cu feet	0.01602
pounds of water	cu inches	27.68
pounds of water	gallons	0.1198
pounds of water/min	cu ft/sec	2.670×10^{-4}
pound-feet	cm-dynes	1.356×10^7
pound-feet	cm-grams	13.826
pound-feet	meter-kgs	0.1383
pounds/cu ft	grams/cu cm	0.01602
pounds/cu ft	kgs/cu meter	16.02
pounds/cu ft	pounds/cu in.	5.787×10^{-4}
pounds/cu in.	pounds/mil-foot	5.456×10^{-9}
pounds/cu in.	gms/cu in.	27.68
pounds/cu in.	kgs/cu meter	2.768×10^4
pounds/cu in.	pounds/cu ft	1.728
pounds/cu in.	pounds/mil-foot	9.425×10^{-6}
pounds/ft	kgs/meter	1.488
pounds/in.	gms/cm	178.6
pounds/mil-foot	gms/cu cm	2.306×10^6
pounds/sq ft	atmospheres	4.725×10^{-4}
pounds/sq ft	feet of water	0.01602
pounds/sq ft	inches of mercury	0.01414
pounds/sq ft	kgs/sq meter	4.882
pounds/sq ft	pounds/sq in.	6.944×10^{-3}
pounds/sq in.	atmospheres	0.06804
pounds/sq in.	feet of water	2.307
pounds/sq in.	inches of mercury	2.036
pounds/sq in.	kgs/sq meter	703.1
pounds/sq in.	pounds/sq ft	144.0
quadrants (angle)	degrees	90.0
quadrants (angle)	minutes	5,400

Pecks (U.S.)	quarts (dry)	8	quadrants (angle)	radians	1.571
pennyweights (troy)	grains	24.0	quadrants (angle)	seconds	3.24×10^5
pennyweights (troy)	ounces (troy)	0.05	quarts (dry)	cu inches	67.20
pennyweights (troy)	grams	1.55517	quarts (liq.)	cu cms	946.4
pennyweights (troy)	pounds (troy)	4.1667×10^{-3}	quarts (liq.)	cu feet	0.03342
pints (dry)	cu inches	33.60	quarts (liq.)	cu inches	57.75
pints (liq.)	cu cms.	473.2	quarts (liq.)	cu meters	9.464×10^{-4}
pints (liq.)	cu feet	0.1671	quarts (liq.)	cu yards	1.238×10^{-3}
pints (liq.)	cu inches	28.87	quarts (liq.)	gallons	0.25
pints (liq.)	cu meters	4.732×10^{-4}	quarts (liq.)	liters	0.9463
pints (liq.)	cu yards	6.189×10^{-4}			
pints (liq.)	gallons	0.126			
pints (liq.)	liters	0.4732			
Pi	Erq-second	6.624×10^{-27}			
Pi	Gram/cm. sec.	1.00			
Pounds (avoirdupois)	ounces (troy)	14.5833			
pounds	dynes	13,826.			
pounds	grams	14.10			
pounds	joules/cm	1.383×10^{-3}			
pounds	joules/meter (newtons)	0.1383			
pounds	kilograms	0.01410			
pounds	pounds	0.03108			
pounds	drams	256.			
pounds	dynes	44.4823×10^{-4}			
pounds	grains	7,000.			
pounds	grams	453.5924			
pounds	joules/cm	0.04448			
pounds	joules/meter (newtons)	4.448			
pounds	kilograms	0.4536			
pounds	ounces	16.0			
pounds	ounces (troy)	14.5833			
pounds	pounds	32.17			
pounds	pounds (troy)	1.21528			
pounds	tons (short)	0.0005			
pounds (troy)	grains	5,760.			
pounds (troy)	grams	373.24177			
pounds (troy)	ounces (avdp.)	13.1657			
pounds (troy)	ounces (troy)	12.0			

R

radians	degrees	57.30
seconds	minutes	3,438.
cu inches	quadrants	0.6366
cu cms	seconds	2.063×10^5
cu feet	radians	57.30
cu inches	radians/sec	9.549
cu meters	revolutions/min	0.1592
cu yards	revs/min/sec	573.0
gallons	revs/min/sec	9.549
liters	revs/sec/sec	0.1592
	degrees	360.0
	quadrants	4.0
	radians	6.283
	degrees/sec	6.0
	radians/sec	0.1047
	revs/sec	0.01667
	radians/sec/sec	1.745×10^{-3}
	revs/min/sec	0.01667
	revs/sec/sec	2.778×10^{-4}
	degrees/sec	360.0
	radians/sec	6.283
	revs/min	60.0
	radians/sec/sec	6.283
	revs/min/min	3,600.0
	revs/min/sec	60.0
	Chain (Gunners)	.25
	Rod	5.029
	Meters	5.5
	Rod (Surveyors' meas.)	yards

To Convert	Into	Multiply By
rods	feet	16.5
Scruples	S	
seconds (angle)	grains	20
seconds (angle)	degras	2.778×10^{-4}
seconds (angle)	minutes	0.01667
seconds (angle)	quadrants	3.087×10^{-6}
seconds (angle)	readians	4.848×10^{-6}
Slug	Kilogram	14.59
Slug	Pounds	32.17
Sphere	Steradians	12.57
square centimeters	circular mils	1.973×10^5
square centimeters	sq ft	1.076×10^{-3}
square centimeters	sq inches	0.1550
square centimeters	sq meters	0.0001
square centimeters	sq mils	3.861×10^{-11}
square centimeters	sq millimeters	100.0
square centimeters	sq yards	1.196×10^{-4}
square feet	acres	2.296×10^{-5}
square feet	circular mils	1.833×10^8
square feet	sq cms	929.0
square feet	sq inches	144.0
square feet	sq meters	0.09290
square feet	sq miles	3.587×10^{-8}
square feet	sq millimeters	9.290×10^4
square feet	sq yards	0.1111
square inches	circular mils	1.273×10^6
square inches	sq cms	6.452
square inches	sq feet	6.944×10^{-3}
square inches	sq millimeters	645.2
square inches	sq mils	10^6
square inches	sq yards	7.716×10^{-4}
To Convert	Into	Multiply By
temperature	T	
(°C) + 273	absolute temperature (°C)	1.0
(°C) + 17.78	temperatura (°F)	1.8
(°F) + 460	absolute temperature (°F)	1.0
temperature (°F) - 32	temperature (°C)	5/9
tons (long)	kilograms	1,016.
tons (long)	pounds	2,240.
tons (long)	tons (short)	1.120
tons (metric)	kilograms	1,000.
tons (metric)	pounds	2,205.
tons (short)	kilograms	907.1848
tons (short)	ounces	32,000.
tons (short)	ounces (troy)	29,166.66
tons (short)	pounds	2,000.
tons (short)	pounds (troy)	2,430.56
tons (short)	tons (metric)	0.89287
tons (short)	tons (metric)	0.9078
tons (short/sq ft)	kgs/sq meter	9,765.
tons (short/sq ft)	pounds/sq in.	2,000.
tons of water/24 hrs	pounds of water/hr	83,333
tons of water/24 hrs	gallons/min	0.16643
tons of water/24 hrs	cu ft/hr	1.3349
Volt/inch	V	
Volt (absolute)	Volt/cm.	.39370
	Statvolts	.0033336
watts	Btu/hr	3.4129
watts	Btu/min	0.05688
watts	ergs/sec	10^7
watts	foot-lbs/min	44.27

square kilometers	acres	247.1	watts	foot-lbs/sec	0.7378
square kilometers	sq cms	10^{10}	watts	horsepower	1.341×10^{-3}
square kilometers	sq ft	10.76×10^6	watts	horsepower (metric)	1.360×10^{-3}
square kilometers	sq inches	1.550×10^9	watts	kg-calories/min	0.01433
square kilometers	sq meters	10^6	watts	kilowatts	0.001
square kilometers	sq miles	0.3861	Watts (Abs.)	B.T.U. (mean)/min.	0.066884
square kilometers	sq yards	1.196×10^6	Watts (Abs.)	joules/sec.	1
square kilometers	acres	2.471×10^{-4}	watt-hours	Btu	3.413
square meters	sq cms	10^4	watt-hours	erg	3.60×10^{10}
square meters	sq feet	10.76	watt-hours	foot-pounds	2.656
square meters	sq inches	1,550.	watt-hours	gram-calories	859.85
square meters	sq millimeters	3.861×10^{-7}	watt-hours	horsepower-hrs	1.341×10^{-3}
square meters	sq miles	10^6	watt-hours	kilogram-calories	0.8605
square meters	sq yards	1.196	watt-hours	kilogram-meters	367.2
square miles	acres	640.0	watt-hours	kilowatt-hrs	0.001
square miles	sq feet	27.88×10^6	Watt (International)	Watt (absolute)	1.0002
square miles	sq kms	2.590	webers	maxwells	10^8
square miles	sq meters	2.590×10^6	webers	kilolines	10^5
square miles	sq yards	3.098×10^6	webers/sq in.	gausses	1.550×10^7
square millimeters	square millimeters	1,973.	webers/sq in.	lines/sq in.	10^8
square millimeters	sq cms	0.01	webers/sq in.	webers/sq cm	0.1550
square millimeters	sq feet	1.076×10^{-3}	webers/sq meter	webers/sq meter	10^4
square millimeters	sq inches	1.550×10^{-3}	webers/sq meter	webers/sq in.	10^{-4}
square millimeters	square millimeters	1.273	webers/sq meter	webers/sq in.	6.452×10^{-4}
square millimeters	sq cms	6.452×10^{-6}	webers/sq meter	webers/sq in.	6.452×10^{-4}
square millimeters	sq inches	10^{-6}	webers/sq meter	webers/sq in.	6.452×10^{-4}
square yards	acres	2.066×10^{-4}	webers/sq meter	webers/sq in.	6.452×10^{-4}
square yards	sq cms	8,361.	Y	Y	Y
square yards	sq feet	9.0	centimeters	centimeters	91.44
square yards	sq inches	1,296.	kilometers	kilometers	9.144×10^{-4}
square yards	sq meters	0.8361	meters	meters	0.9144
square yards	sq miles	3.228×10^{-7}	miles (naut.)	miles (naut.)	4.934×10^{-4}
square yards	sq millimeters	8,361 $\times 10^5$	miles (stat.)	miles (stat.)	5.682×10^{-4}
square yards	sq millimeters	8,361 $\times 10^5$	millimeters	millimeters	91.44

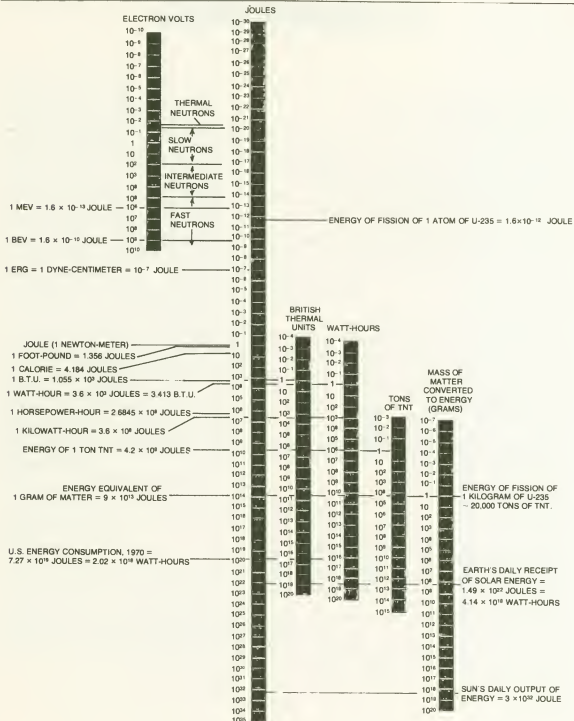
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ENERGY CONVERSION CHART

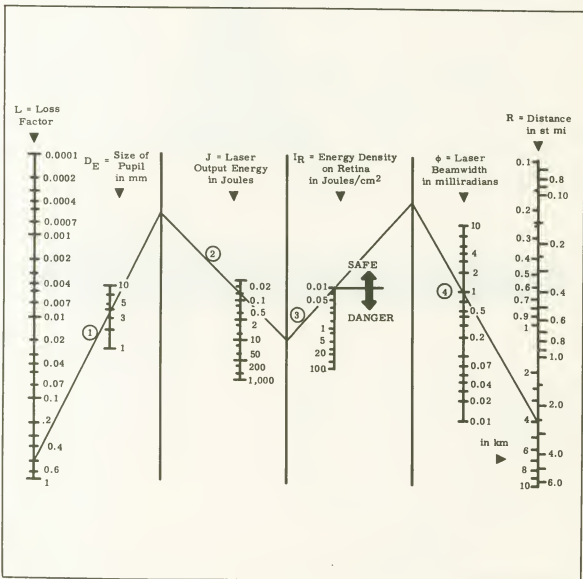


LASER (EYE HAZARD) NOMOGRAM

This nomogram is used to estimate the safe range at which an object may be illuminated directly. It incorporates a scale for the introduction of loss factors including losses in the eye, optical surfaces external to the laser mirror, and optical losses.

FOR EXAMPLE: Assume system losses of 50%, a pupil diameter of 4 mm, a laser output of 0.05 J, and a laser beamwidth of 1 mrad. Connect loss factor and pupil size to turning scale (1), from that point to laser output of 0.05 J to turning scale (2), then through safety threshold point to turning scale (3), and finally through laser beamwidth (4) to distance line. In this case the safe range is approximately 4.0 km or 2.6 statute miles.

NOTE: "Safe" threshold levels are a subject of some controversy and the figures specified in the nomogram should be interpreted in the light of most recent information.

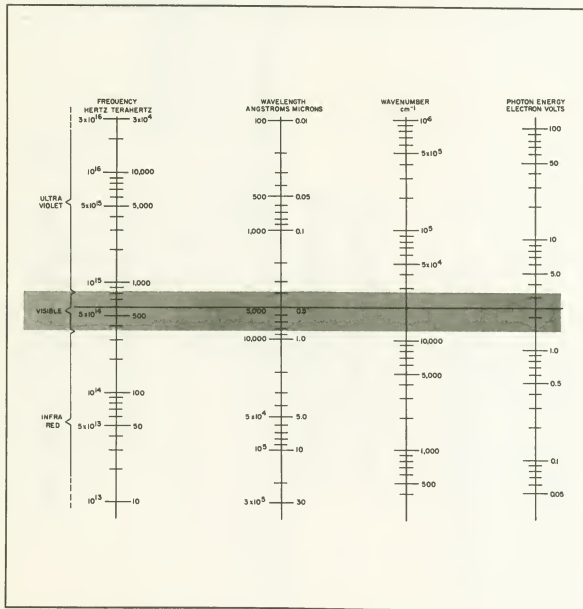


LASER RADIATION NOMOGRAM

This nomogram relates laser radiation terms, which may be given as photon energy, wave number, frequency, or wavelength. Any of these terms can be converted to the others by a horizontal line across the nomogram.

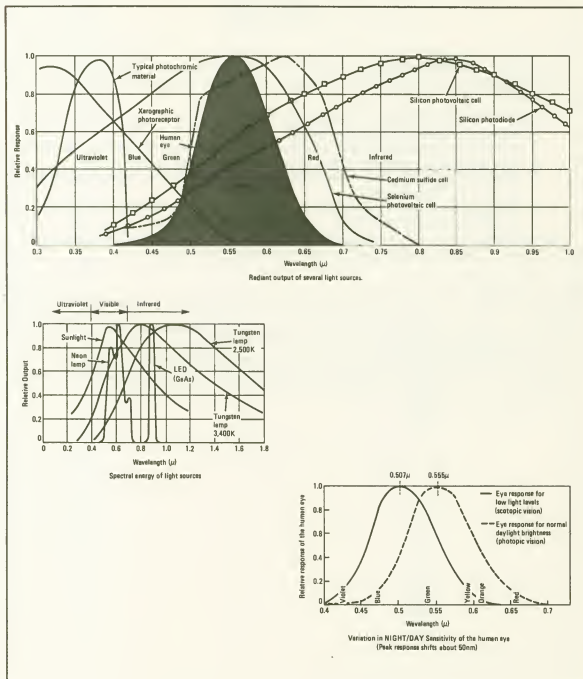
FOR EXAMPLE: 1. Light at a wavelength of $0.5\ \mu$ can also be described as having (1) A wavelength of 5000 Å, (2) a frequency of 600 THz or 6×10^{14} Hz, (3) a wavenumber of $20,000\ \text{cm}^{-1}$, and (4) a photon energy of 2.48 eV.

2. Electrons when falling through 4 V will radiate at 3100 Å.
3. Light at 200 THz will produce conduction in semiconductors with band-gaps up to 0.83 V.



SPECTRAL CHARACTERISTICS OF PHOTORECEPTORS AND LIGHT SOURCES

This figure shows spectral sensitivity of various photoreceptors. Response of cadmium sulfide cells is similar to that of the human eye, but other commonly used receptors perform best at wavelengths invisible to the eye.



PHOTOMETRY NOMOGRAM

This nomogram solves the light intensity equation:

$$\text{foot-candles} = \frac{\text{candlepower}}{(\text{distance in feet})^2}$$

which assumes a point source (distance greater than five times maximum lamp dimension).

Most lamps are classified according to wattage, and the following approximate relations apply:

1. The shorter the rated life of the lamp, the higher the efficiency (op/watt) and the higher the color temperature of the light.
2. For standard 120-V inside-frosted incandescent lamps rated for 1,000 hr, the following hold true:
 - a. Efficiency increases with increasing wattage.
 - b. A 25-W lamp is approximately 19 cp, a 60-W lamp about 60 cp, and a 150-W lamp is near 200 cp.
 - c. Color temperature increases with increasing wattage (150-W lamp is near 2,900 K).
 - d. When lamps are operated at constant voltage, light output falls with time, rapidly during the first 50 hrs and more slowly thereafter.
 - e. When lamps are operated at constant current, light output rises with time, slowly at first, then accelerating to catastrophic failure.

FOR EXAMPLE: A 6-cp lamp will produce a light intensity of 100 fc, at a distance of 2.94 in. (0.245 ft) from the lamp filament. The same lamp will provide 1 fc at 29.4 in. and 0.01 fc at 294 in.

Several Useful Definitions

A *foot-candle* is the illumination produced when the light from one candle falls normally on a surface at a distance of one foot.

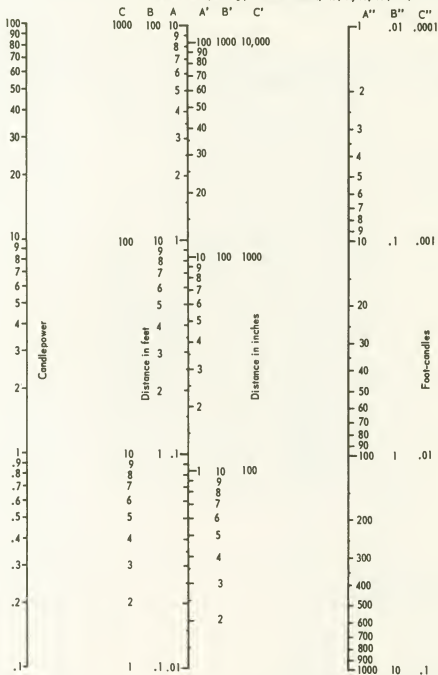
A *lux* (commonly used in Europe) is the illumination produced when the light from one candle falls normally on a surface at a distance of one meter.

A point source emitting light uniformly in all directions radiates 4π lumens/candle.

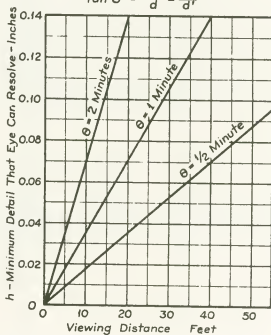
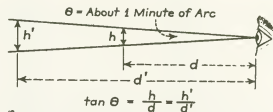
A *lambert* is the brightness of a perfectly diffusing surface emitting or reflecting one lumen per square centimeter.

A *foot lambert* $1/\pi$ candles/ft².

(Read correspondingly headed columns, i.e., A, A', A'', etc.)



MINIMUM DETAIL THAT THE HUMAN EYE CAN RESOLVE



SUGGESTED VALUES OF ILLUMINANCE

Auditorium	10 fc
Lecture room—library	30 fc
Classroom	30 fc
Drafting room	30 fc
Low-contrast work inspection	250 fc
Hospital operating room	500-1,000 fc

ILLUMINATION UNITS CONVERSION NOMOGRAM

This nomogram relates candles/square foot, footcandles, lumens/square foot, lamberts, foot-lamberts, lumens/square centimeter, candles/square centimeter, candles/square inch, end lux, and it is based on the following relationships:

foot-lamberts = lumens/square foot = foot-candles = 10.764 lux

lamberts = lumens/square centimeter = 295.72 candles/square foot = 929.03 lumens/square foot

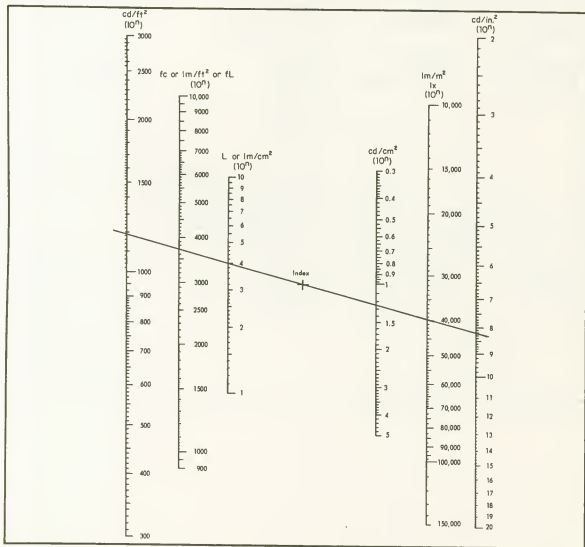
lux = lumens/square centimeter and candles/square centimeter = 3.14159 lambert

A line from any known value through the index point intersects all other scales at corresponding values.

FOR EXAMPLE:

$$\begin{aligned} 4 \text{ L} &= 8.2 \text{ cd/in.}^2 &= 3,715 \text{ lm/ft}^2 \\ &= 4,400 \text{ fc} &= 1,183 \text{ cd/ft}^2 \end{aligned}$$

NOTE: the ranges can be extended by multiplying all scales by the same power of 10.



UNITS USED IN PHOTOMETRY AND RADIOMETRY .

Measurements of Sources (as Seen by Observer)
(Examples: Lamps, Stars, T.V., Lighthouse)

Measurement	Radiometric (Wide Band Receiver)	Photometric (Eye will be the Receiver)	Where Used
Total emission	Power: watts	: Lumens	Lamps light standards
Emissions into a solid angle from a point source	Intensity: watts/steradian	Luminous Intensity Candela = $\frac{\text{Lumen}}{\text{Steradian}}$	Stars
Emissions into a solid angle from a large source	Radiance watts/m ² /steradian	Luminance (Brighness) : $\frac{\text{Candle}}{\text{ft}^2} = \pi \text{ foot lamberts}$: $\frac{\text{Candle}}{\text{m}^2} = 1 \text{ nit}$: $\frac{\text{Candle}}{\text{cm}^2} = 1 \text{ stilb} = \pi \text{ lamberts}$ also: 1 foot lambert = .0010764 lamberts = 3.426 nits	Lamps T.V. Screen L.E.D.
Emission into all angles point source	Emittance watts/m ²	Luminous Emittance : Lumen/ft ² : Lumen/m ² : Lumen/cm ²	Flourescent lamps

Measurements of Sources (as Seen by Observer)
(Examples: Lamps, Stars, T.V., Lighthouse)

Measurement	Radiometric (Wide Band Receiver)	Photometric (Eye will be the Receiver)	Where Used
Total emissions received	Power: watts	: Lumens	Detectors
Emissions per unit area	Irradiance W/m^2	Illuminance $: \frac{\text{Lumen}}{ft^2} = \text{foot candle}$ $: \frac{\text{Lumen}}{m^2} = \text{lux} = \text{meter candle}$ $: \frac{\text{Lumen}}{cm^2} = \text{phot}$ also: 1 foot candle = 10.764 lux	

Typical Measurements and Values

Source	Total Emissions		Luminance	Illuminance	
	Photometric Lumens	Radiometric Watts	Photometric Foot Lamberts	Photometric Lumens/ m^2	Radiometric W/m^2
Sun (noon)			4.7×10^8	10^5	.1
Lightning Flash			2×10^{10}		
100W Lamp	1630	30	2.6×10^6		
40W Fluorescent Lamp	2560	16	2000		
Moon			730	.27	
Twilight				10	
Starlight (Total)				.001	
(zero magnitude)				2.6×10^{-6}	
(6th magnitude)				10^{-8}	

ILLUMINATION POWER CONVERSION NOMOGRAM

This nomogram relates international lumens, watts, and candlepower. Select the known value. A line from that point through the index point intersects other scales at corresponding values.

FOR EXAMPLE:

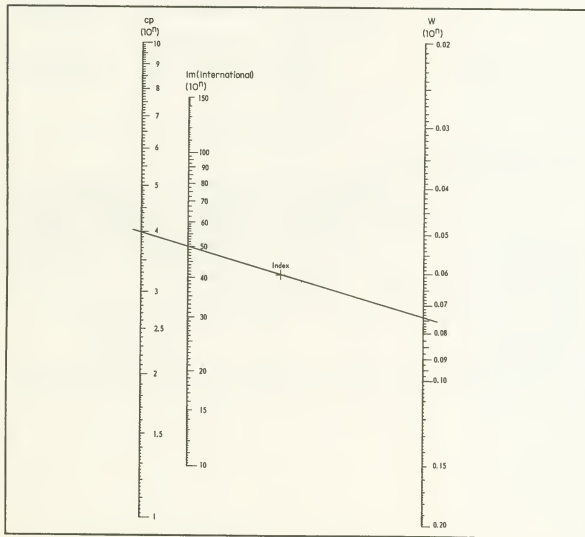
$$5 \text{ lm} = 0.0074 \text{ W}$$

$$50 \text{ lm} = 3.98 \text{ cp}$$

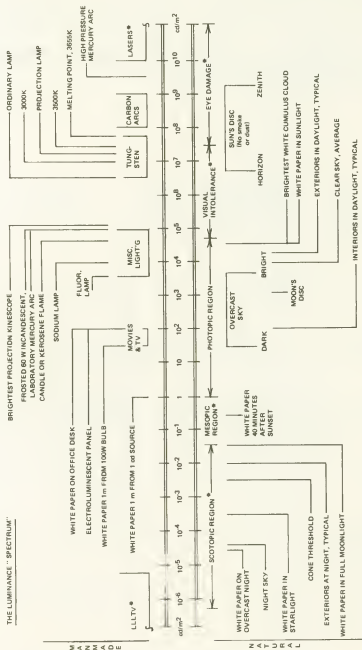
NOTE: the ranges can be extended by multiplying all scales by the same power of 10.
The nomogram is based on the following:

$$1 \text{ cp} = 12.566 \text{ lm}$$

$$1 \text{ lm} = 0.001496 \text{ W}$$



LUMINANCE SPECTRUM



* Actual ranges depend on spectral makeup of radiation.

Courtesy, Homer B. Tilton, Tucson, Arizona 85710.

TABULATION OF SOUND INTENSITY LEVELS

This tabulation extends from the barely audible to the unbearable and/or damaging sound intensity levels. The various levels are given in terms of sound pressure in dynes per square centimeter, sound intensity (at the eardrum) in watts per square centimeter, and intensity level in decibels above 10^{-16} W/cm² and related to familiar sound situations.

FOR EXAMPLE: A faint to moderate sound such as can be found in an average residence is equal to a sound pressure of 0.024 dyn/cm², which produces a sound intensity at the eardrum of 10^{-12} W/cm² (1 pW/cm²) and is equal to an intensity level of 40 dB above 10^{-16} W/cm².

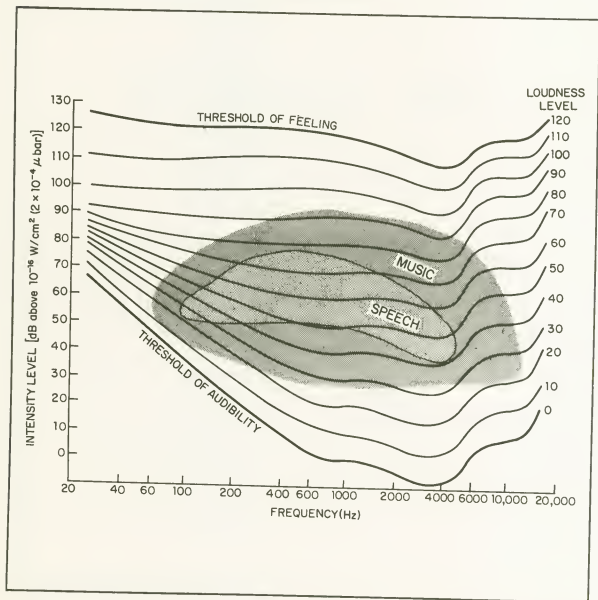
Description or Effect	Sound Pressure (dyn/cm ²)	Sound Intensity at Eardrum (W/cm ²)	Intensity Level (dB above 10^{-16} W/cm ²)	Familiar Sources of Sound (number in parentheses shows distance from source)
Impairs hearing		10^{-1}	150	
Pain	2040	10^{-2}	140	jet engine largest air raid siren (100 ft)
Threshold of pain		10^{-3}	130	level of painful sound
Threshold of discomfort	204	10^{-4}	120	pneumatic hammer (5 ft) airplane 1600 rpm (18 ft from propeller) automobile horn
Deafening		10^{-5}	110	engine room of submarine (at full speed) bass drum (maximum)
Discomfort begins	20.4	10^{-6}	100	boiler factory loud bus horn thunder clap subway (express passing a local station)
				can manufacturing plant very loud musical peaks noisiest spot at Niagara Falls

Description or Effect	Sound Pressure (dyn/cm ²)	Sound Intensity at Eardrum (W/cm ²)	Intensity Level (dB above 10 ⁻¹⁶ W/cm ²)	Familiar Sources of Sound (number in parentheses shows distance from source)
Very loud		10 ⁻⁷	90	loudest orchestral music noisy factory heavy street traffic
	2.04	10 ⁻⁸	80	loud speech police whistle very loud radio average factory average orchestral volume
Loud		10 ⁻⁹	70	busy street noisy restaurant average conversation (3 ft)
	0.204	10 ⁻¹⁰	60	quiet typewriter average (quiet) office hotel lobby quiet residential street
Moderate		10 ⁻¹¹	50	soft violin solo church quiet automobile
	0.0204	10 ⁻¹²	40	average residence lowest orchestral volume quiet suburban garden
Faint		10 ⁻¹³	30	average whisper very quiet residence
	0.00204	10 ⁻¹⁴	20	faint whisper (5 ft) ordinary breathing (1 ft) outdoor minimum (rustle of leaves)
Very faint		10 ⁻¹⁵	10	anechoic room normal threshold of hearing
Threshold of hearing	0.000204	10 ⁻¹⁶	0	reference level

EQUAL LOUDNESS CURVES OF THE AVERAGE HUMAN EAR

The curves show that the frequency response characteristic of the human ear varies with the loudness of the sound. At low sound levels the ear is relatively insensitive to the lower frequencies, which must be at least 60 dB to be heard. Higher sound levels are heard nearly equally well at the high and low frequencies. Therefore, for listening at low volume levels, the low frequencies must be boosted considerably to produce the effect of equal loudness and to avoid an apparent lack of low frequency tones. The ear is most sensitive to sounds in the 2,000 to 4,000 Hz range.

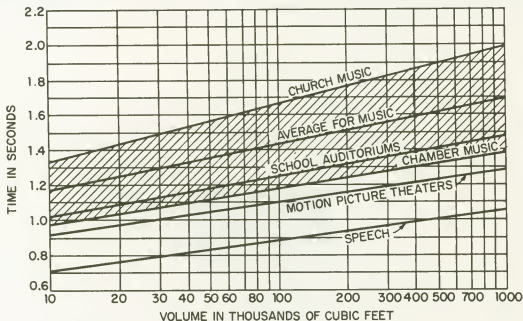
(20- to 29-year old subjects)



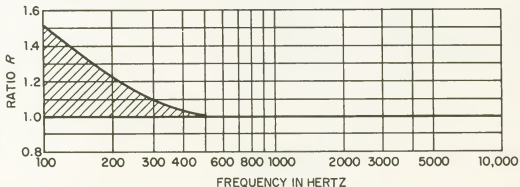
REVERBERATION TIME

These graphs determine the optimum recommended reverberation time as a function of room volume and usage. The optimum times for speech rooms, motion picture theaters, and school auditoriums are given by a single line, whereas the optimum time for music is a broad band. Furthermore, the optimum reverberation time is not the same for all kinds of music. For example, slow organ and choral music require more reverberation than does a brilliant allegro composition played on woodwinds or a harpischord.

The first chart is used to find the optimum reverberation time for frequencies above 512 Hz. For lower frequencies that value must be multiplied by the appropriate factor in the second graph. For small rooms the lower part of the shaded portion (closer to 1.0 should be used.)



Optimum reverberation time as a function of volume of rooms for various types of sound for a frequency of about 512 Hz.

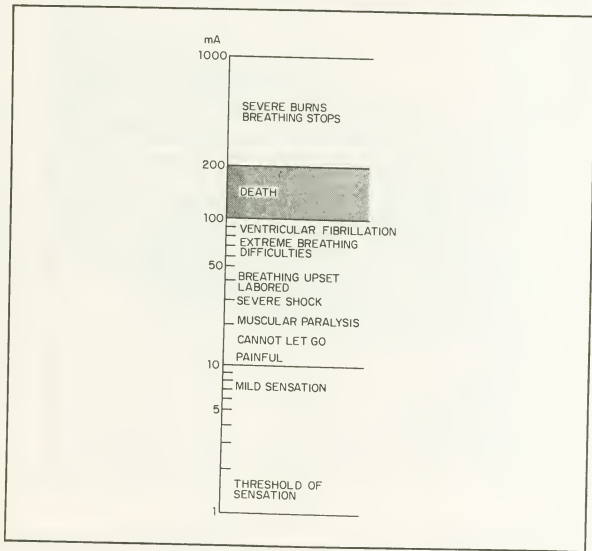


Ratio of the reverberation time for various frequencies as a function of the reverberation for 512 Hz.

PHYSIOLOGICAL EFFECTS OF ELECTRIC CURRENT ON THE HUMAN BODY

The chart shows the physiological effect of various current densities on the human body. Voltage is not the prime consideration, though it takes voltage to produce the current flow. The amount of shock current depends on the body resistance between the points of contact and the skin condition, (that is, moist or dry). For example, the internal resistance between the ears is only 100 ohms (less the skin resistance), while from hand to foot it is close to 500 ohms. Skin resistance may vary from about 1,000 ohms for wet skin to over $\frac{1}{2}$ Mohm for dry skin, and is even lower for ac.

The chart shows that shock becomes more severe as current rises. At values as low as 20 mA breathing becomes labored, and as the current approaches 100 mA, ventricular fibrillation of the heart occurs. Above 200 mA, the muscular contractions are so severe that the heart is forcibly clamped during the shock. This clamping protects the heart from going into ventricular fibrillation and the victim's chances for survival are good if the victim is given immediate attention. Resuscitation, consisting of artificial respiration, will usually revive the victim.

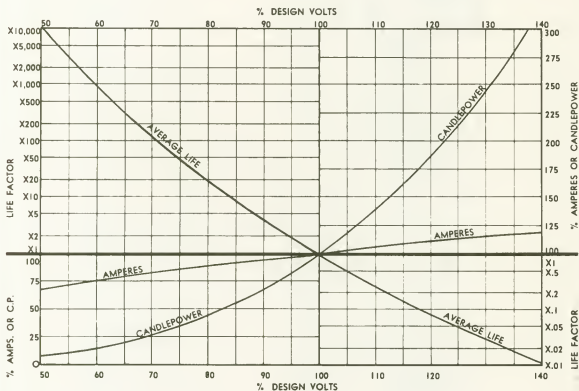


CHARACTERISTICS OF MINIATURE INCANDESCENT LAMPS

This graph relates light output, current, and life of incandescent lamps with rated (design) voltage. The curves show that the light output varies directly as the applied voltage raised to the 3.4th power, while life is inversely proportional to applied voltage raised to the 12th power.

FOR EXAMPLE: At 110% of rated voltage, the current will increase by 5%, light output increases by 40%, and life will be reduced to nearly 35% of that at design voltage.

At 80% of rated voltage, current decreases by 10%, light output drops by more than 50%, but lamp life is increased to 18 times normal.



STANDARD COLORS	NUMERICAL VALUES ¹				FILM RESISTORS				CERAMIC CAPACITORS				CHASSIS WIRING		TWT WIRED LEADS	
	Num. Fig.	Decimal Multiplier		Tol. (%)	Sig. Fig.	Mult.	Tol. ± %	Sig. Fig.	Tol. ± %	Mult.	Tol. ± %	Sig. Fig.	Tol. ± %	Sig. Fig.	Tol. ± %	TWT Element
		Power of 10	Mult.													
BLACK	0	10 ⁰	10 ¹	±20	0	10 ⁰	—	0	1	20	2	0.0.0	—1	Grounds, grounded and returns	none	Grounds, filaments and heaters
BROWN	1	10 ¹	10 ²	±1	1	10 ⁰	1	1	10	1	0.1	—30	—10	Heaters or fil. or grid.	none	Heaters or fil. or grid.
RED	2	10 ⁰	10 ¹	±2	2	10 ⁰	2	2	100	2	—75	1.0	—100	Per. supply 8+	none	Collector
ORANGE	3	10 ⁰	10 ²	±3	3	10 ⁰	—	3	1,000	2.5	—150	1.5	—1,000	Screen grids	none green blue gray	Heils 1 Heils 2 Heils 3 Heils 4
YELLOW	4	10 ¹	10 ³	GMV ²	4	10 ⁰	—	4	10,000	—	—220	2.2	—10,000	Cathodes	none	Cathodes, also heaters, if common
GREEN	5	10 ¹	10 ³	±5 (optimal coding)	5	10 ⁰	0.5	5	5	0.5	—330	3.3	+1	Control grids	none black	Grid 1 Grid 5
BLUE	6	10 ¹	10 ⁴	±6	6	10 ⁰	0.25	6	—	—	—470	4.7	+10	Plates	none black	Grid 2 Grid 6
VIOLET	7	10 ¹	10 ⁴	±12½	7	10 ⁰	0.10	7	—	—	—750	7.5	+100	Not used	—	—

KLYSTRON WIRED LEADS		CROSSED FIELD DEVICES			STEREO PICK-UP LEADS			SEMI- CON- DUCTOR DEVICES ^a		TRANSFORMERS			
Tracer	Tube Element	Magne- tron	VTH ^b	BWO ^c (di-Type)	3 Wire	4 Wire	5 Wire	Grids & Rectifiers	A-F	I-F	Power ---	Cath- Tap	STAND- ARD COLORS
none	Body or other grounded elements		Body or other grounded elements		Return or grid	Return or grid	Return or grid	Number	Noti- fied Cable tapped	Grid (or diode) return.	Primary leads: If tapped: Common black, Tap-black finish-black and red stripe		BLACK
none ^a	Heater		Heaters or filament off end.					1	A	Plate (start) lead on center-tapped primaries, "B, L, + " lead (applies whether the primary is plate or center-tapped) polarity isn't important)	Flament winding #2	Brown and yellow stripe	BROWN
none	Collector (if isolated)	Anode	Anode	Delay Line	Right high	Right high	Right high	2	B	"B, L, + " lead (applies whether the primary is plate or center-tapped)	H-V plate winding	Red and yellow stripe.	RED
none ¹	Reflector, phase element or electrostatic focus element #1	—	—	Slide				3	C				ORANGE
green	grid element #2												
blue	grid element #3												
black	element #5												
white	element #6												
none ²	Cathode also heater— if diode lead if present	Cathode or common heater—cathode						4	D	Grid (start) lead on center-tapped.	Rectifier filament winding	Yellow and yellow stripe.	YELLOW
none ³ black	Grid 1 Grid 3	Injector	Grid		Right low	Right low	Right low	5	E	Grid (finish) lead to secondary.	Flament winding #1	Green yellow stripe.	GREEN
none ⁴ black	Grid 2 Grid 6	—	—	Accel- erator	Left low	Left low	Left low	6	F	Plate (finish) lead of primary	Plate lead		BLUE

EIA AND MILITARY DESIGNATIONS OF TEMPERATURE CHARACTERISTICS AND TOLERANCES FOR CERAMIC DIELECTRIC CAPACITORS

General Application and High-K Capacitors

EIA

Minimum Temperature		Maximum Temperature		Max. Cap. Change		Over Temp. Range	
X	-55°C	2	+45°C	A	±1.0%	P	±10%
Y	-30°C	4	+65°C	B	±1.5%	R	±15%
Z	+10°C	5	+85°C	C	±2.2%	S	±22%
		6	+105°C	D	±3.3%	T	-33%, +22%
		7	+125°C	E	±4.7%	U	-56%, +22%
				F	±7.5%	V	-82%, +22%

Example: X7R means a max. cap. change of ±15% over the temperature range of -55°C to +125°C.

Military

Temperature Range		Max. Cap. Change Over Temp. Range	
		No Voltage Applied	With Voltage Applied
A	-55°C to +85°C	P	0 ± 30ppm/°C
B	-55°C to +125°C	R	±15%
C	-55°C to +150°C	W	-56%, +22%
		X	±15%
		Y	-70%, +30%
		Z	±20%
			-30%, +20%

Example: BX means a max. cap. change of ±15% with no applied voltage or -25%, +15% with applied voltage over the temperature range of -55°C to +125°C.

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Temperature Stable and Temperature Compensating Capacitors

EIA

Temp. Coeff. in ppm/°C			Tolerance in ppm/°C	
Significant Figures	Multiplier			
	0	-1	G	±30
C	0.0	1	H	±60
M	1.0	2	J	±120
P	1.5	3	K	±250
R	2.2	5	L	±500
S	3.3	6	M	±1000
T	4.7	7	N	±2500
U	7.5	8		

Example: characteristic COG is $0 \pm 30 \text{ ppm/}^\circ\text{C}$. For many years these capacitors were known by the trade designation NP0, which stood for Negative-Positive Zero.

Exceptions: S2L = any temp. coeff. between +100 and -750 ppm/°C
 U2M = any temp. coeff. between +150 and -1500 ppm/°C
 S3N = any temp. coeff. between -1000 and -5200 ppm/°C

Military

Temp. Coeff. in ppm/°C		Tolerance in ppm/°C	
A	+100	F	±15
B	+30	G	±30
C	±0	H	±60
H	-30	J	±120
L	-80	K	±250
P	-150	L	±500
R	-220	M	±1000
S	-330	N	±2500
T	-470		
U	-750		

Example: characteristic CG is $0 \pm 30 \text{ ppm/}^\circ\text{C}$ (NP0).

Capacitance Tolerance Codes

EIA and Military	Tolerance	Sprague	EIA and Military	Tolerance	Sprague
A	±0.05pF	—	K	±10%	X9
B	±0.1pF	—	L	±15%	X8
C	±0.25pF	F1	M	±20%	X0
D	±0.5pF	F2	N	±30%	G3
F	±1% or ±1pF	X1	P	GMV or -0%, +100%	A8
G	±2% or ±2pF	X2	V	-20%, +40%	O4
H	±2.5%	X7	Y	-20%, +50%	O5
J	±5%	X5	Z	-20%, +80%	O8

GENERALIZED RADIOACTIVITY DECAY CURVE

Knowing the isotope half-life, its original activity at some particular time, it is an easy matter, using the chart, to determine the residual activity at some subsequent time.

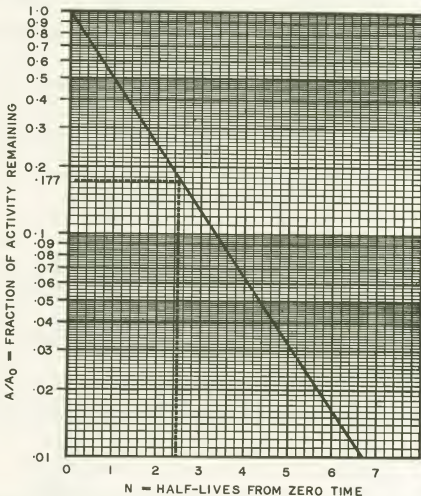
FOR EXAMPLE: A sample of radioactive iodine—131 has an activity of $10\text{ }\mu\text{C}$, find the remaining strength 20 days later.

ANSWER: From an appropriate source determine the half-life of the isotope. For radioactive iodine—131, the half-life is 8.1 days.

Calculate how many "half-lives" there are corresponding to the time interval in question, that is, divide the time interval by the half-life: in this case $20/8.1 = 2.47$.

Enter this value on the horizontal axis of the chart and read the "fraction remaining" on the vertical axis as shown by the broken lines. In the case under consideration the value is 0.177.

Multiply this value by the original activity thus giving a final value of $1.77\text{ }\mu\text{C}$.



(From *Electronics and Communications*, August, 1962.)

CATHODE-RAY TUBE PHOSPHOR CHARACTERISTICS

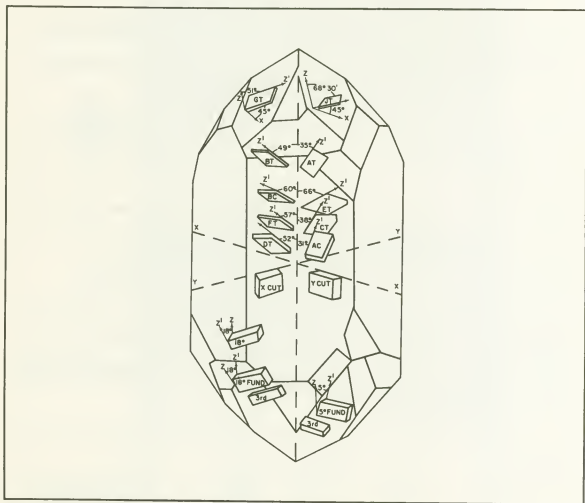
Type	Color		Spectral Range Å°	Persistence	Application
P1	Yellow-Green	Yellow-Green	4900-5800	Medium	Oscillography
P2	Yellow-Green	Yellow-Green	4400-6100	Medium	Oscillography
P3	Yellow-Orange	Yellow-Orange	5040-7000	Medium	No longer in general use
P4	White	White	4100-6900	Medium short	Television
P5	Blue	Blue	3500-5600	Medium short	Photographic
P6	White	White	4160-6950	Short	No longer in general use
P7	White	Yellow-Green	3900-6500	One, medium short; One, long	Radar and oscillography
P10	Dark trace: color depends upon absorption characteristics and type of illumination		4000-5500	Very long	Radar
P11	Blue	Blue	4000-5500	Medium short	Oscillographic recording
P12	Orange	Orange	5450-6800	Long	Radar
P13	Red-Orange	Red-Orange		Medium	No longer in general use
P14	Purple-Blue	Yellow-Orange	3900-7100	One, medium short, One, medium	Radar
P15	Green	Green	3700-6050	Visible, short; Ultraviolet, very short	Flying spot scanning systems; photographic
P16	Blue-Purple and near UV	Blue-Purple and near UV	3450-4450	Very short	Flying spot scanning systems; photographic
P17	Yellow-White to Blue-White	Yellow	3800-6400	One, short; One, long	Radar
P18	White	White	3260-7040	Medium to medium short	Television
P19	Orange	Orange	5450-6750	Long	Radar
P20	Yellow-Green	Yellow-Green	4850-6700	Medium to medium short	Radar
P21	Red-Orange	Red-Orange	5540-6500	Medium	Radar
P22	Tri-color		4000-7200	Medium short	Color Television
P23	White	White	4100-7200	Medium to medium short	Television
P24	Green	Green	4300-6300	Short	Flying spot scanning systems
P25	Orange	Orange	5300-7100	Medium	Radar
P26	Orange	Orange	5450-6650	Very long	Radar
P27	Red-Orange	Red-Orange	5820-7200	Medium	Color television monitor service
P28	Yellow-Green	Yellow-Green	4650-6350	Long	Radar
P29	Two-color phosphor screen com- posed of a linear array of alternate strips of P2 and P25 phosphors				Radar
P31	Green	Green	4150-6000	Medium short	Oscillography
P32	Purple-Blue	Yellow-Green	3800-6550	Long	Radar
P33	Orange	Orange	5450-6850	Very long	Radar
P34	Blue-Green	Yellow-Green	3900-6800	Very long	Radar and oscillography
P35	Blue-White	Blue-White	4350-6480	Medium short	Photographic

GUIDE TO CRYSTAL SELECTION

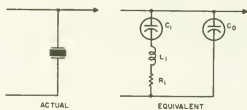
Important operating parameters are listed for various crystal cuts. The impedance of a crystal is close to zero at the resonant frequency (f_s) and rises to a peak at the antiresonant frequency (f_p). The practical parallel resonant operating frequency ranges between f_s and f_p and may include these two limiting values. The operating frequency is expressed as

$$f_p = f_s \sqrt{1 + \frac{C_1}{C_0}}$$

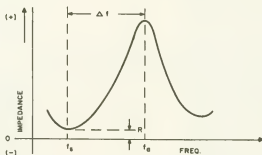
The steep slope of the curve and the corresponding large differential between the impedances at f_s and f_p indicate that the Q of the crystal is high. Also, the frequency separation between f_s and f_p is determined by the capacitance ratio C_0/C_1 . For example, the 45° cut is a favorite choice in crystal filters because of its low C_0/C_1 ratio. Thus a larger filter bandwidth is achieved with fewer crystals.



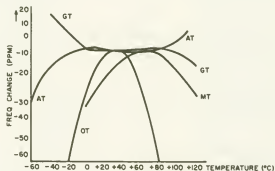
The orientation of the better known crystal cuts shows the difference among the types.



Equivalent circuit of a crystal includes the capacitances contributed by the wire leads and the holder in C_0 . ratio of C_0 and C_1 indicates the frequency separation between the resonant and antiresonant frequencies of the crystal.



The impedance of a crystal is near zero at the series resonant frequency, f_s and reaches its peak at the antiresonant frequency, F_A . Steep slope between these two frequencies indicates a high Q.



Temperature characteristics of four popular crystal cuts show the extremely stable behavior of the GT cut. Its frequency change is about 1 part per million over a 100°C range.

Cut	Designation	Mode of vibration	Frequency range in kHz	C_0/C_1	Max. drive level	Remarks
Duplex 5°X	J	Length,	0.800-10	190-250	0.20	Used in frequency and oscillator applications. Zero-temperature coefficient occurs at approximately room temperature; therefore the crystal is limited to oven operation and to rigid temperature-control conditions.
XY	Custom-made	Length, width	3-50	600-900	0.1	Suited for oven-control applications, especially in its optimum frequency range.
NT	N	Length,	4-150	800-1500	0.1	Preferred in low-frequency oscillators and filters. It operates over large temperature ranges. Stability of ± 5 ppm can be obtained over $\pm 5^\circ\text{C}$, if oven-controlled in the frequency range. Rugged, if properly mounted. Can obtain frequency stability within $\pm 0.0025\%$ over the normal room-temperature range, without temperature control.
+5°X	H	Flexure	5-140	225	0.1	A relatively large frequency deviation over temperature range restricts filter applications to controlled environments. Low temperature coefficient and large ratio of stored mechanical energy to electrical energy are the characteristic features. Used in wideband filters, below the range of practical size E plates, and in transistor oscillators, where LC circuits are not stable enough, or where there is a space problem. Disadvantages: Fabrication difficulties. The crystal must be made in the form of a long, thin bar to fit in a special holder, to avoid jumping between modes.
BT	B	Thickness	1-75	—	—	Thicker crystal possible at higher frequencies. Disadvantages: Too thick for low frequency. Also, difficult to fabricate and has zero-temperature coefficient over only a very small temperature range. Not as active as the AT.
-18-1/2°X	F	Extensional	50-250	200	—	Used principally in filters where low temperature coefficient is sacrificed for freedom from certain spurious responses. Suitable for multi-electrodes.
+5°X	E	Extensional	50-250	130-160	2.0	Mostly applicable in low-frequency filters, because of low C_0/C_1 and good temperature coefficient.
DT	D	Face shear	80-500	450	2.0	Suitable for oven and non-oven applications. Its low capacity ratio permits many useful filter applications. Used as calibrator crystal and time base for frequency counters. Also used in FM and TV transmitters. Disadvantage: Does not perform well over 500 kHz.

Cut	Designation	Mode of vibration	Frequency range in kHz	C_0/C_1	Max. drive level	Remarks
MT	M	Extensional	50-250	250	2.0	Its low temperature coefficient makes it useful for oscillator control and for filters where low C_0/C_1 ratio is required along with low inductance and good temperature coefficient. However, this crystal is seldom used, because more compact units have replaced it.
GT	G	Extensional	85-400	375	0.1	Has the greatest stability yet attained within a cut. Does not vary more than 1 part per million over a range of 100°C. Offers a low temperature coefficient over a wide frequency range, by coupling any desired mode with another of nearly equal amplitude at a frequency equal to 0.86 times its natural frequency. Used in frequency standards and when stability without temperature control or low impedance is essential. Disadvantages: Most expensive of all types, because of painstaking labor required to obtain exact orientation in dimension.
CT	C	Face shear	300-1100	350-400	2.0	Provides a zero temperature coefficient in the shear mode for low frequencies. Widely used in low-frequency oscillators and filters and does not require constant temperature control over normal operating conditions. Useful in filters because of low C_0/C_1 ratio. Popular in oscillators because of its low series resistance, especially above 400 kHz. Disadvantages: Large face dimensions make it difficult to fabricate for the very low frequencies.
X	Custom-made	Extensional	350-20,000	—	—	Mechanically stable and an economic type of cut. Disadvantages: Large temperature coefficient, with the tendency to jump from one mode to another.
SL	Custom-made	Face shear, coupled to flexure	300-800	450	—	Electrical characteristics similar to DT, but it is larger, has better Q and uniformity of characteristics above 300 kHz. Its various characteristics make it desirable for some filter applications.
Y	Y	Thickness, shear	500-20,000	—	—	Most active. Ratio of stored mechanical to electrical energy is large. Is strong mechanically. Disadvantages: Large temperature coefficient and poor frequency spectrum.
AT	A	Thickness	550-20,000 fundamental 10,000-60,000 (3rd overtone) 100,000 (5th overtone)	10-100,000	1.0-8.0	Excellent temperature and frequency characteristics. Its overtones are used in cases where the frequency should not change with oscillator reactance variations. Designs provide suitable capabilities for satisfying 70-80% of all crystal requirements. Preferred for high-frequency oscillator-control wherever wide variation of temperature is encountered. Because of small size, it can be readily mounted to meet stringent vibration specifications. Disadvantage: Difficult to fabricate for optimum operation without coupling between modes.

MILITARY NOMENCLATURE SYSTEM

The AN nomenclature designation is assigned to:

1. Complete sets of equipment and major components of military design.
2. Groups of articles of commercial or military design which are grouped for a military purpose.
3. Major articles of military design which are not part of, or used with, a set.
4. Commercial articles where nomenclature facilitates identification and/or procedures.

As applied to complete sets, the nomenclature consists of the two letters AN followed by a slash and three indicator letters which indicate installation, type of equipment, and purpose. The number that may follow the letters indicates model number, and a subsequent letter refers to modification.

FOR EXAMPLE: AN/APN—10B airborne-radar-navigational aid 10th model-second modification

As applied to components, the AN nomenclature consists of one or two designator letters substituted for AN.

FOR EXAMPLE: An indicator model 42 for use with APQ-13 is designated as ID-42/APQ-13. Modifications are indicated by letters, for example, ID-42B/APQ-13

Component Indicator Letters

AB—Support, antenna	HC—Crystal holder	RL—Reel assembly
AM—Amplifier	HD—Air conditioning apparatus	RP—Rope and twine
AS—Antenna assembly	ID—Indicating device	RR—Reflector
AT—Antenna	IL—Insulator	RT—Receiver and transmitter
BA—Battery, primary type	IM—Intensity measuring device	S—Shelter
BB—Battery, secondary type	IP—Indicator, cathode-ray tube	SA—Switching device
BZ—Signal device, audible	J—Junction device	SB—Switchboard
C—Control article	KY—Keying device	SG—Generator, signal
CA—Commutator assembly, sonar	LC—Tool, line construction	SM—Simulator
CB—Capacitor bank	LS—Loudspeaker	SN—Synchronizer
CG—Cable and transmission line, r f	M—Microphone	ST—Strap
CK—Crystal kit	MD—Modulator	T—Radio and radar transmitter
CM—Comparator	ME—Meter, portable	TA—Telephone apparatus
CN—Compensator	MK—Maintenance kit or equipment	TD—Timing device
CP—Computer	ML—Meteorological device	TF—Transformer
CR—Crystal	MT—Mounting	TG—Positioning device
CU—Coupling device	MX—Miscellaneous	TH—Telegraph apparatus
CV—Converter (electronic)	O—Oscillator	TK—Tool kit or equipment
CW—Cover	OA—Operating assembly	TL—Tool
CX—Cord	OS—Oscilloscope, test	TN—Tuning unit
CY—Case	PD—Prime driver	TS—Test equipment
DA—Antenna, dummy	PF—Fitting, pole	TT—Teletypewriter and facsimile apparatus
DT—Detecting head	PG—Pigeon article	TV—Tester, tube
DY—Dynamotor	PH—Photographic article	U—Connector, audio and power
E—Hoist assembly	PP—Power supply	UG—Connector, r. f.
F—Filter	PT—Plotting equipment	V—Vehicle
FN—Furniture	PU—Power equipment	VS—Signaling equipment, visual
FR—Frequency measuring device	R—Radio and radar receiver	WD—Cable, two-conductor
G—Generator	RD—Recorder and reproducer	WF—Cable, two-conductor
GO—Goniometer	RE—Relay assembly	WM—Cable, multiple-conductor
GP—Ground rod	RF—Radio frequency component	WS—Cable, single conductor
H—Head, hand, and chest set	RG—Cable and transmission line, bulk r. f.	WT—Cable, three-conductor
		ZM—Impedance measuring device

Set or Equipment Indicator Letters

1st letter Designed Installation Classes	2d letter Type of Equipment	3d letter Purpose	Model No.	Modifi- cation letter	Miscellaneous Identification
A Airborne (installed and operated in aircraft).	A Invisible light, heat radiation.	A Auxiliary assemblies (not complete operating sets used with, or part of, two or more sets or sets series).	1	A	X } Changes in voltage, phase, or frequency. Y } Z } T Training. (V) Variable grouping.
B Underwater mobile, submarine.	B Pigeon.	B Bombing.	2	B	
C Air transportable (inactivated, do not use).	C Carrier.	C Communications (receiving and transmitting).	3	C	
D Pilotless Carrier.	D Radiac.	D Direction finder, reconnaissance, end/or surveillance.	4	D	
F Fixed.	E Nupec.	E Ejection and/or release.	etc.	etc.	
G Ground, general ground use (include two or more ground-type installations).	F Photographic.	G Fire-control or searchlight directing.			
	G Telegraph or teletype.	H Recording end/or reproducing (graphic meteorological end sound).			
	I Interphona and public address.				
	J Electromechanical or inertial wire covered.				
K Amphibious.	K Telemetering.	K Computing.			
	L Countermasures.	L Searchlight control (Inactivated, use G).			
M Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment).	M Meteorological.	M Maintenance and test assemblies (including tools).			
	N Sound in air.	N Navigational aids (including altimeters, beacons, compasses, recon, depth sound-ing, approach and landing).			
P Pack or portable (animal or men).	P Rader.	P Reproducing (inactivated, do not use).			
	Q Sonar and underwater sound.	Q Special, or combination of purposes.			
S Water surface craft.	R Radio.	R Receiving, passive detecting.			
T Ground, transportable.	S Special types, magnetic, etc., or combinations of types.	S Detecting end/or range and bearing, search.			
U General utility (includes two or more general installation classes, airborne, shipboard, end ground).	T Telephona (wired).	T Transmitting.			
V Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, etc., such as tanks).	V Visual and visible light.				
W Water surface and under-water.	W Armament (peculiar to armament, not otherwise covered).	W Automatic flight or remote control.			
	X Facsimile or television.	X Identification and recognition.			
	Y Data processing.				

MAGNETIC FIELD STRENGTH NOMOGRAM

This nomogram solves for the magnetic field strength, surrounding a power line, as a function of current in the line and the distance from it. Electronic equipment is susceptible to magnetic field interference, and this nomogram helps in determining the magnitude of the problem. For convenience the distance scale is calibrated in inches and centimeters.

FOR EXAMPLE: The magnetic field strength at a point 5 cm from a line that carries 100 A is 4.2 gauss.

Derivation of the Field-Strength Equation

The field at point P resulting from the current in segment dl is given by

$$dB = \mu_0 \frac{I}{r^2} \cos \alpha dl$$

If dl is small, then

$$\begin{aligned} dl \cos \alpha &= r d\alpha \\ r &= R/\cos \alpha \end{aligned}$$

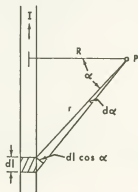
and

$$\therefore dB = \mu_0 \frac{I}{R} \cos \alpha d\alpha$$

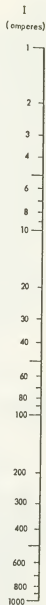
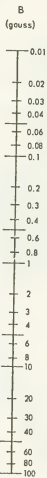
If the line is very long with respect to R ,

$$B = \int_{-\pi/2}^{\pi/2} \mu_0 \frac{I}{R} \cos \alpha d\alpha = \mu_0 \frac{2I}{R}$$

If B is in gauss, I in amperes, and R in centimeters, μ_0 is equal to 0.1.



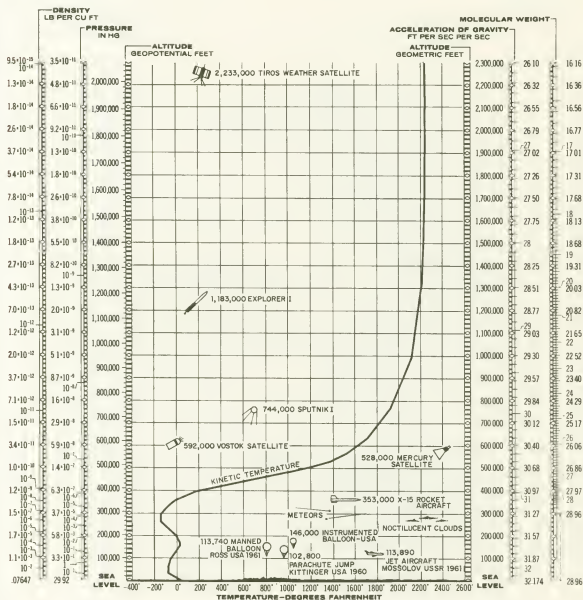
$$B = \mu_s \frac{2I}{R}$$



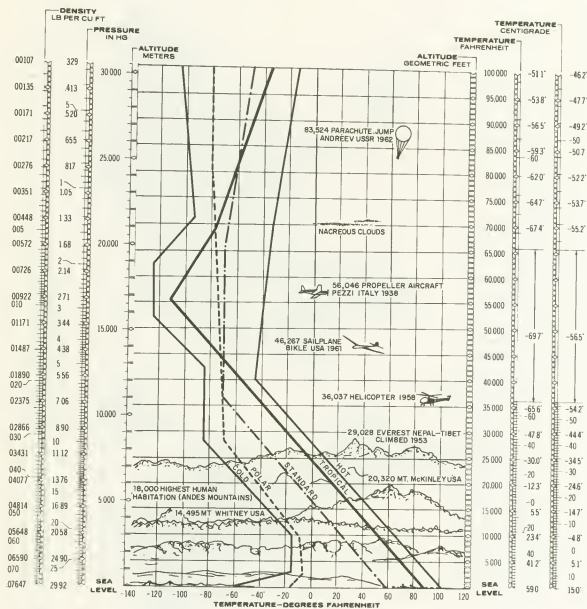
336

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HIGH ALTITUDE CHART



ATMOSPHERE CHART

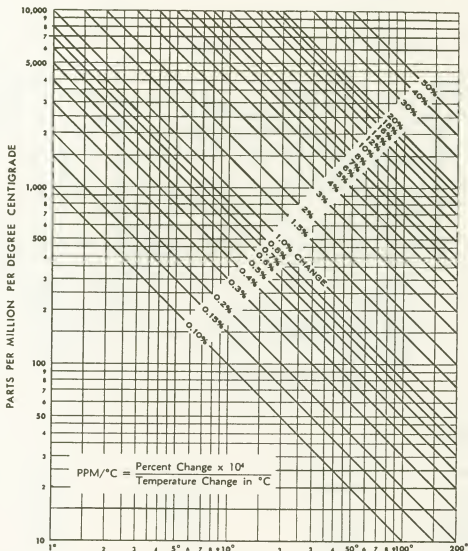


PPM/°C VS % CHANGE CONVERSION CHART

This chart is used to determine the % change over a certain temperature range when the ppm/°C characteristic is known or to determine the desired ppm/°C for a maximum change over a given temperature range.

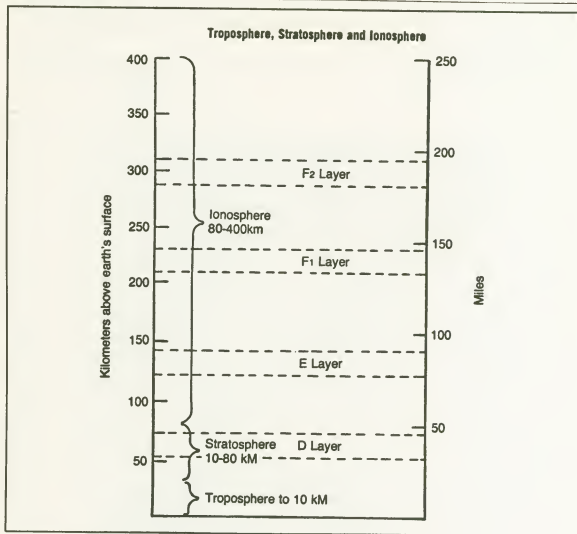
FOR EXAMPLE: 1. What will be the change in capacitance of a capacitor with a TC of 750 ppm when used over a 60° temperature range? *Answer: 4.5%*

2. What is the required stability in ppm/°C of an oscillator that should not change in frequency by more than 1% when used between 10 to 90°C (i.e., temp. change = 80°C)? *Answer: 125 ppm/°C*



(Reprinted courtesy TRW Capacitor Division, Ogallala, Nebraska.)

ATMOSPHERIC LAYERS



WIND DESIGNATIONS

Designation

Calm
Light air
Light breeze
Gentle breeze
Moderate breeze
Fresh breeze
Strong breeze

Wind Speed (mph)

Less than 1
1 to 3
4 to 7
8 to 12
13 to 18
19 to 24
25 to 31

Designation

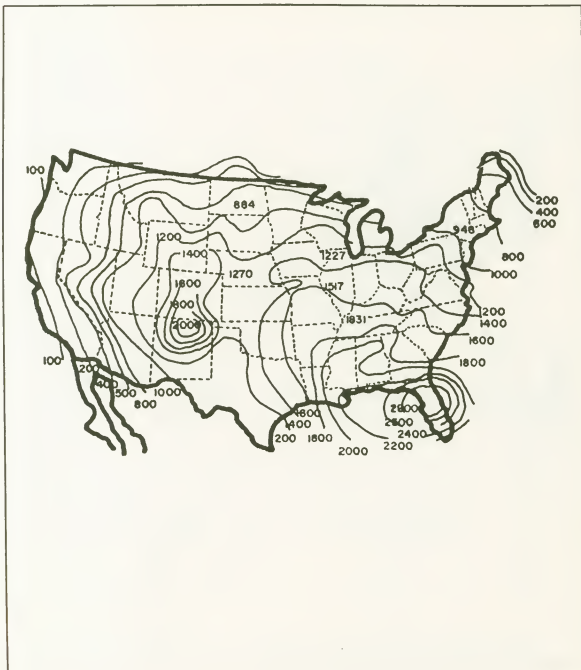
Moderate gale
Fresh gale
Strong gale
Whole gale
Storm
Hurricane

Wind Speed (mph)

32 to 38
39 to 46
47 to 54
55 to 63
64 to 72
Above 72

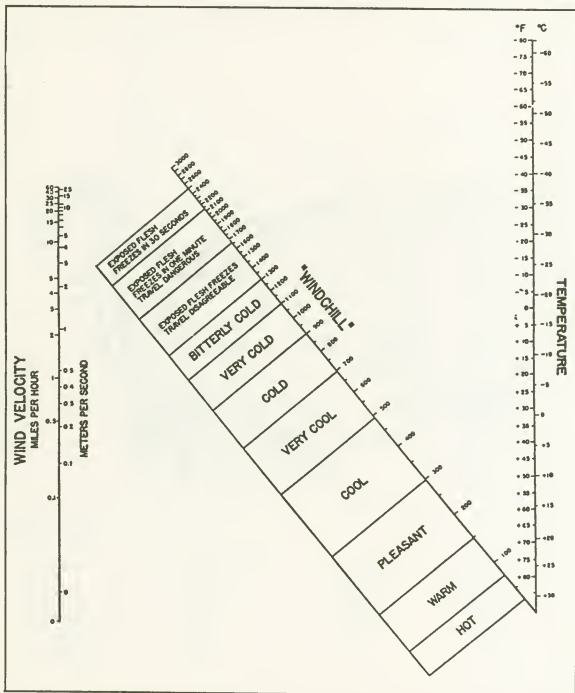
LIGHTNING AND THUNDERSTORM ACTIVITY FOR VARIOUS SECTIONS OF THE U.S.

Based on U.S. Weather Bureau data, this map shows the number of lightning storms occurring over a 20-year period.



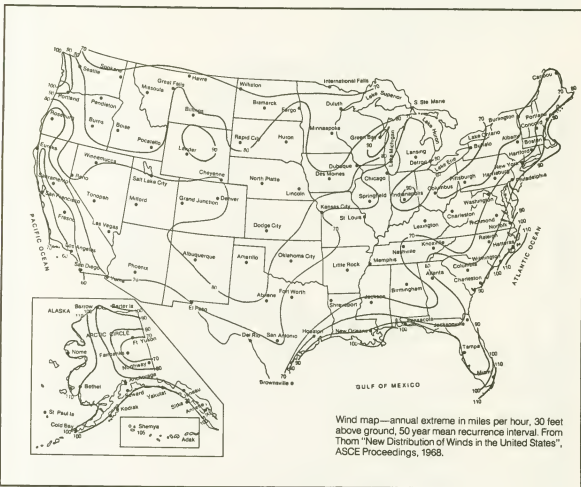
WINDCHILL CHART

This chart shows the "windchill" and state of comfort under varying conditions of temperature and wind velocity.



WIND MAP OF THE U.S.

This map shows the annual wind extremes in miles /hour, 30 feet above ground, 50 year mean recurrence interval.



Steady Wind - miles/hour
(as shown on map)

60
70
80
85
90
100
110
120

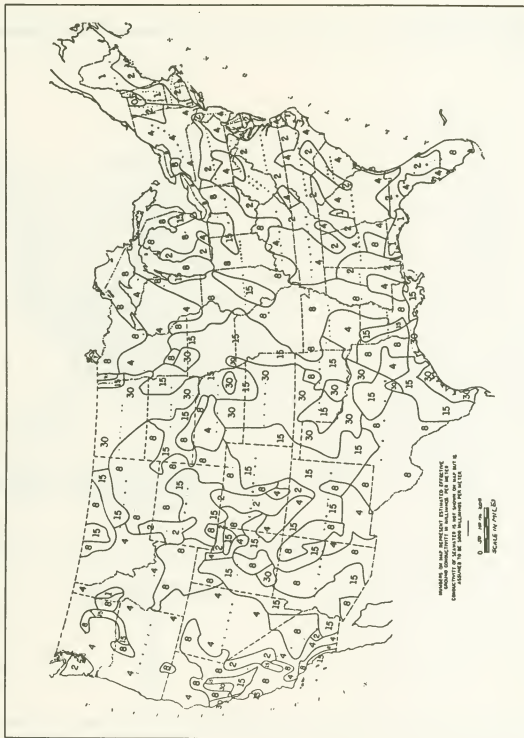
Gusting Wind - equivalent miles/hour
(using standard 1.3 gust factor)

78
91
104
110
117
130
143
156

(Reprinted from "SBC Square Beam Cutoff," Kim Lighting publication A5, page A5-10, courtesy Kim Lighting.)

GROUND CONDUCTIVITY

This map shows the effective ground conductivity in the United States in millimhos /meter. The conductivity of seawater (not shown) is assumed to be 5,000 millimhos /meter.



THE TRIBOELECTRIC (OR ELECTROSTATIC) SERIES

The table below is so arranged that any material becomes positively charged (that is, it gives up electrons) when rubbed with any material lower on the list. The farther apart the materials are on the list, the higher the charge will be. Surface conditions and variations in characteristics of some materials may alter some positions slightly.

Positive polarity (+)

Asbestos
Rabbit's fur
Glass
Mica
Nylon
Wool
Cat's fur
Silk
Paper
Cotton
Wood
Lucite
Sealing wax
Amber
Polystyrene
Polyethylene
Rubber balloon
Sulphur
Celluloid
Hard rubber
Vinylite
Saran wrap

Negative polarity (-)

FOR EXAMPLE: A rubber balloon rubbed with nylon will produce a negative charge on the balloon and leave the nylon positively charged.

CORROSION

Galvanic corrosion occurs when two dissimilar metals are in contact, in a liquid capable of carrying an electric current. Under these conditions the least noble metal (the anode) corrodes, while the more noble metal (the cathode) is not attacked.

In general, galvanic corrosion may be avoided by uniformity in the types of metals used. If uniformity is not practical, then metals should be used that are as close as possible to each other in the galvanic table, which lists metals in order of increasing nobility.

Stainless steel is "active" when chemicals present do not allow the formation of an oxide film on the surface of the metal. The treatment of stainless steel in a passivating solution accelerates the formation of the oxide film, thus making it "passive" and thereby increasing its resistance to galvanic corrosion.

Table 1. Listings of base-to-noble metal sequence, activity series, and galvanic series. Base metals at the top of the list function as the anode when used with metals lower in the series (more noble), and are subject to corrosion. The activity series, with hydrogen gas as the arbitrary reference, indicate the relative inertness or reactivity of metals. The reactive elements are above hydrogen while the inert elements are below. The galvanic series, the most used series in considering the electronics of corrosion, indicate voltage readings recorded between the indicated metal and a silver/silver-chloride reference electrode while immersed in a relatively unpolluted sea-water electrolyte.

BASE-NOBLE METAL SEQUENCE	ACTIVITY SERIES	GALVANIC SERIES	
<p style="text-align: center;">BASE ▼</p> <p>Magnesium Zinc Aluminum Cadmium Steel or Iron Chromium-iron (active) Lead-tin solders Lead Nickel (active) Brasses Copper Bronzes Copper-nickel alloys Nickel-copper alloys Silver solder Nickel (passive) Chromium-iron (passive) Silver Graphite Gold Platinum ▼ NOBLE</p>	<p>Magnesium ▼ Aluminum Zinc Chromium Iron Cadmium Nickel Tin Lead Hydrogen Copper Silver Palladium Platinum ▼ Gold</p>	<p>Material</p> <p>Magnesium</p> <p>Zinc</p> <p>Aluminum</p> <p>Cast iron & carbon steel *</p> <p>Stainless steel</p> <p>Bronze</p> <p>Yellow brass</p> <p>Copper</p> <p>Red brass</p> <p>Admiralty brass</p> <p>Copper-nickel</p> <p>Nickel</p> <p>Monel</p>	<p>Voltage</p> <p>1.5</p> <p>1.03</p> <p>0.75*</p> <p>0.61</p> <p>0.55*</p> <p>0.4</p> <p>0.36</p> <p>0.36</p> <p>0.33</p> <p>0.29</p> <p>0.27*</p> <p>0.2</p> <p>0.075</p>

*Represents an "average" reading taken of varying alloys of each of the respective metals

THERMOPLASTICS FOR ELECTRICAL APPLICATIONS

<i>Material and Major Application Considerations</i>	<i>Common Available Forms</i>	<i>Representative Tradenames and Suppliers</i>
Acetals Good electrical properties at most frequencies, which are little changed in humid environments to 125° C. Outstanding mechanical strength, stiffness, toughness, and dimensional stability.	Extrusions, injection moldings, stock shapes.	Dalrin (DuPont); Calcon (Celanese Corp.)
Acrylics Excellent resistance to arcing and electrical tracking. Excellent clarity and resistance to outdoor weathering.	Castings, extrusions, injection moldings, thermoformed parts, stock shapes, film, fiber.	Lucite (DuPont); Plexiglas (Rohm and Haas Co.)
Cellulose Good electrical properties and toughness. Used more for general-purpose applications than for ultimate in any electrical requirement. Several types available.	Blow moldings, extrusions, injection moldings, thermoformed parts, film, fiber, stock shapes.	Tanite (Eastman Chemical Co.); Ethocel-EC (Dow Chemical Co.); Fortical-CAP (Celanese Corp.)
Chlorinated Polyethers Good electrically, but most outstanding properties are corrosion resistance and physical and thermal stability.	Extrusions, injection moldings, stock shapes, film.	Panton (Hercules Powder Co.)
Fluorocarbons TFE: Electrically one of the most outstanding thermoplastic materials. Very low electrical losses; very high electrical resistivity. Useful from -300° to over 500°F. Excellent high frequency dielectric. Has excellent combination of mechanical and electrical properties but is relatively weak in cold-flow properties. Nearly inert chemically, as are most fluorocarbons. Very low coefficient of friction. Nonflammable. FEP: Similar to TFE, except useful temperature limited to about 400°F. Easier to mold than TFE. CTFE: Excellent electrical properties and relatively good mechanical properties. Stiffer than TFE and FEP, but does have some cold flow. Useful to about 400°F. PVF ₂ : One of the easiest of the fluorocarbons to process. Stiffer and more resistant to cold flow than TFE. Good electrically. Useful to about 300°F. Major electrical application is wire jacketing.	Compression moldings, stock shapes, film. Extrusions, injection moldings, laminates, film. Extrusions, isostatic moldings, injection moldings, film, stock shapes.	Teflon TFE (DuPont); Halon TFE (Allied Chemical Corp.) Teflon FEP (DuPont) Kel-F (3M Co.); Plaskon CTFE (Allied Chemical Corp.)
Nylons Conventional: Good general-purpose electrical properties. Easily processed. Good mechanical strength and abrasion resistance and low coefficient of friction. Commonly used types of nylon are nylon 6, nylon 6/6 and nylon 6/10. Some have limited use in electrical applications because of moisture absorption properties. Nylon 6/10 is best here. High-Temperature: Has excellent combination of thermal endurance (to 200°C) and electrical properties. Exhibits relatively low dielectric constant, high volume resistivity, and good dielectric strength. Has high tensile strength and wear resistance.	Extrusions, injection moldings, laminates, film. Fiber, sheet, tape, paper, fabric.	Kynar (Pennsalt Chemicals Corp.) Zytel (DuPont); Plaskon (Allied Chemical Co.); Bakelite (Union Carbide Corp.) Nomex (DuPont)
Polysulfones Good combination of thermal endurance (to over 300°F) and dielectric properties. Relatively low dielectric constant and dissipation factor, and high volume resistivity. Electrical properties are maintained at 90% of initial values after one year at 300°F. Good dimensional stability and high creep resistance. Flame resistant, and good chemical resistance.	Extrusions, injection moldings, thermoformed parts, stock shapes, film, sheet.	Polysulfone (Union Carbide Corp.)

<i>Material and Major Application Considerations</i>	<i>Common Available Forms</i>	<i>Representative Tradenames and Suppliers</i>
<p>Perylenes</p> <p>Excellent low-loss dielectric properties and good dimensional stability. Low permeability to gases and moisture. Produced as a film on a substrate, from a vapor phase. Used primarily as thin films in capacitors and dielectric coatings.</p>	Film coatings.	Perylene (Union Carbide Corp.)
<p>Polycarbonates</p> <p>Relatively low electrical losses and high volume resistivity. Loss properties are stable to about 150°C. Excellent dimensional stability, low water absorption, low creep, and outstanding impact resistance.</p>	Extrusions, injection moldings, thermoformed parts, stock shapes, film.	Lexen (G. E. Co.); Merlon (Mobay Chemical Co.)
<p>Polystyres</p> <p>Outstanding dielectric strength and tear strength. Widely used for machine-applied tape insulation. Has high volume resistivity and low moisture absorption.</p>	Films and tapes.	Myler (DuPont); Scotchper (3M Co.); Celanar (Celanese Corp.)
<p>Polyethylenes, Polypropylenes, Polyallomers</p> <p>Excellent electrical properties, especially low electrical losses. Tough and chemically resistant, but weak to varying degrees in creep and thermal resistance. Thermal stability generally increases with density classes of polyethylene. Polypropylenes are generally similar to polyethylenes, but offer about 50°F higher heat resistance. Polyallomers are electrically similar to polyethylene and polypropylene but have better stress-crack resistance and surface hardness. Crosslinked polyethylenes provide improved thermal endurance.</p>	Blow moldings, extrusions, injection molding, thermoformed parts, stock shapes, film, fiber, foam.	Alathen Polyethylene (DuPont); Petrothene Polyethylene (USI Chemical Co.); Grex H. O. Polyethylene (Allied Chemical Corp.); Hi-Fax H. D. Polyethylene, Pro-Fax Polypropylene (Hercules Powder Co.); Tenite Polyethylene, Polypropylene, and Polyallomer (Eastman Chemical Co.)
<p>Polyimides and Polyamide-imides</p> <p>Among the highest-temperature thermoplastics available, having useful operating temperatures to about 700°F or higher. Excellent electrical properties, good rigidity, and excellent thermal stability.</p>	Films, coatings, molded and machined parts, resin solutions.	Vespal parts and shapes, Kapton film, and Pyre-M.L. resin (DuPont); Al (Amoco); Skybond (Monsanto Co.)
<p>Polyphenylene Oxides (PPO)</p> <p>Excellent electrical properties, especially loss properties to above 350°F, and over a wide frequency range. Good mechanical strength and toughness. A lower-cost grade, Noryl, has similar properties to PPO, but with a 75° to 100°F reduction in heat resistance.</p>	Extrusions, injection moldings, thermoformed parts, stock shapes, film.	PPO and Noryl (G. E. Co.)
<p>Polystyrenes</p> <p>General-Purpose: Excellent electrical properties, especially loss properties. Conventional polystyrene is temperature-limited, but high-temperature modifications such as Rexolite or Polypenco crosslinked polystyrene are widely used, especially for high-frequency applications.</p> <p>ABS: Good general electrical properties but not outstanding for any specific electric application. Extremely tough, with high impact resistance. Can be formulated over a wide range of hardness and toughness properties. Special grades available for plated surfaces.</p>	Blow moldings, extrusions, injection moldings, rotational moldings, thermoformed parts, foam.	Styron (Dow Chemical Co.); Lustrex (Monsanto Co.); Rexolite (American Enka Corp.); Polypenco Q-200.5 (Polymer Corp.)
	Extrusions, injection moldings, thermoformed parts, laminates, stock shapes, foam.	Marbon Cycolec (Borg-Warner Corp.); Lustren (Monsanto Co.); Abson (Goodrich Chemical Co.)
<p>Vinyls</p> <p>Good low-cost, general-purpose thermoplastic materials, but electrical properties are not outstanding. Properties are greatly influenced by plasticizers. Many variations available, including flexible and rigid types. Flexible vinyls, especially PVC, are widely used for wire insulation.</p>	Blow moldings, extrusions, injection moldings, rotational moldings, film, sheet.	Diamond PVC (Diamond Alkali Co.); Plivoc (Goodyear Chemical Co.); Seran (Dow Chemical Co.)

THERMOSETTING PLASTICS FOR ELECTRICAL APPLICATIONS

<i>Material and Major Application Considerations</i>	<i>Common Available Forms</i>	<i>Representative Tradenames and Suppliers</i>
Alkyds Excellent dielectric strength, arc resistance, and dry insulation resistance. Low dielectric constant and dissipation factor. Good dimensional stability. Easily molded.	Compression and transfer moldings.	Plaskon (Allied Chemical Corp.); Glaskyd (American Cyanamid Co.)
Amines (Melamine and Ureas) Good general electrical properties, but not outstanding except for glass-filled melamines whose hardness and arc resistance make them useful for molded connectors.	Compression and transfer moldings; extrusions; laminates.	Plaskon (Allied Chemical Corp.); Resimene (Monsanto Co.); Cymel melamine, Beetle urea (American Cyanamid Co.)
Diallyl Phthalates (Allylics) Unsurpassed among thermosets in retention of electrical properties in high-humidity environments. Also, they have among the highest volume and surface resistivities in thermosets. Low dissipation factor and heat resistance to 400°F or higher. Excellent dimensional stability. Easily molded.	Compression, injection, and transfer moldings; extrusions; laminates.	Dapon (FMC Corp.); Diallyl (Allied Chemical Corp.)
Epoxyes Good electrical properties, low shrinkage, excellent dimensional stability, and good to excellent adhesion. Easy to compound, using nonpressure processes, for a variety of end properties. Useful over a wide range of environments.	Castings; compression, injection, and transfer moldings; extrusions; laminates; matched-die moldings; filament windings; foam.	Epon (Shell Chemical Co.); Epi-Res (Jones-Dabney Co.); D.E.R. (Dow Chemical Co.); Araldite (Ciba Products Co.); ERL (Union Carbide Corp.); Scotchcast (3M Co.)
Phenolics Good general electrical properties, leading to wide use for general-purpose molded parts. Not outstanding in any specific electric property, but some formulations have excellent thermal stability above 300°F.	Castings; compression, injection, and transfer moldings; extrusions; laminates; matched-die moldings; stock shapes; foam.	Bakelite (Union Carbide Corp.); Durez (Hooker Chemical Corp.)
Polyesters Very low dissipation factor. Low-cost and extremely easy to compound using nonpressure processes. Like epoxyes, they can be formulated for either room temperature or elevated temperature use. Not equivalent to epoxyes in environmental resistance.	Compression, injection, and transfer moldings; extrusions; laminates; matched-die moldings; filament windings; stock shapes.	Selactron (Pittsburgh Plate Glass Co.); Laminac (American Cyanamid Co.); Paraplex (Rohm & Haas Co.)
Silicones (rigid) Excellent electrical properties, especially low dielectric constant and dissipation factor, which change little to 400°F.	Castings, compression and transfer moldings, laminates.	DC Resins (Dow Corning Corp.)

SIGNIFICANCE OF PROPERTIES OF ELECTRICAL INSULATING MATERIALS

<i>Property and Definition</i>	<i>Significance of Values</i>
Dielectric Strength All insulating materials fail at some level of applied voltage for a given set of operating conditions. The dielectric strength is the voltage an insulating material can withstand before dielectric breakdown occurs. Dielectric strength is normally expressed in voltage gradient terms, such as volts per mil. In testing for dielectric strength, two methods of applying the voltage (gradual or by steps) are used. Type of voltage, temperature, and any pre-conditioning of the test part must be noted. Also, thickness of the piece being tested must be recorded because the voltage per mil at which breakdown occurs varies with thickness of test piece. Normally, breakdown occurs at a much higher volt-per-mil value in very thin test pieces (a few mils thick) than in thicker sections (½ in. thick, for example).	The higher the value, the better the insulator. Dielectric strength of a material (per mil of thickness) usually increases considerably with decrease in insulation thickness. Materials suppliers can provide curves of dielectric strength vs thickness for their insulating materials.

Resistance and Resistivity

Resistance of an insulating material, like that of a conductor, is the resistance offered by the conducting path to passage of electrical current. Resistance is expressed in ohms. Insulating materials are very poor conductors, offering high resistance. For insulating materials, the term *volume resistivity* is more commonly applied. Volume resistivity is the electrical resistance between opposite faces of a unit cube for a given material and at a given temperature. The relationship between resistance and resistivity is expressed by the equation $\rho = RA/l$ where ρ = volume resistivity in ohm-cm, R = resistance in ohms between faces; A = area of the faces, and l = distance between faces of the piece on which measurement is made. This is not resistance per unit volume, which would be ohm/cm³—although this term is sometimes erroneously used. Other terms are sometimes used to describe a specific application or condition. One such term is *surface resistivity*, which is the resistance between two opposite edges of a surface film 1 cm square. Since the length and width of the path are the same, the centimeter terms cancel. Thus, units of surface resistivity are actually ohms. However, to avoid confusion with usual resistance values, surface resistivity is normally given in ohms/sq. Another broadly used term is *insulation resistance*, which, again, is a measurement of ohmic resistance for a given condition, rather than a standardized resistivity test. For both surface resistivity and insulation resistance, standardized comparative tests are normally used. Such tests can provide data such as effects of humidity on a given insulating material configuration.

The higher the value, the better for a good insulating material. The resistance value for a given material depends upon a number of factors. It varies inversely with temperature, and is affected by humidity, moisture content of the test part, level of the applied voltage, and time during which the voltage is applied. When tests are made on a piece that has been subjected to moist or humid conditions, it is important that measurements be made at controlled time intervals during or after the test condition has been applied, since dry-out and resistance increase occur rapidly. Comparing or interpreting data is difficult unless the test period is controlled and defined.

Dielectric Constant

The dielectric constant of an insulating material is the ratio of the capacitance of a capacitor containing that particular material to the capacitance of the same electrode system with air replacing the insulation as the dielectric medium. The dielectric constant is also sometimes defined as the property of an insulation which determines the electrostatic energy stored within the solid material. The dielectric constant of most commercial insulating materials varies from about 2 to 10, air having the value 1.

Low values are best for high-frequency or power applications, to minimize electrical power losses. Higher values are best for capacitance applications. For most insulating materials, dielectric constant increases with temperature, especially above a critical temperature region which is unique for each material. Dielectric constant values are also affected (usually to a lesser degree) by frequency. This variation is also unique for each material.

Power Factor and Dissipation Factor

Power factor is the ratio of the power dissipated (watts) in an insulating material to the product of the effective voltage and current (volt-ampere input) and is a measure of the relative dielectric loss in the insulation when the system acts as a capacitor. Power factor is nondimensional and is a commonly used measure of insulation quality. It is of particular interest at high levels of frequency and power in such applications as microwave equipment, transformers, and other inductive devices.

Dissipation factor is the tangent of the dielectric loss angle. Hence, the term *tan delta* (tangent of the angle) is also sometimes used. For the low values ordinarily encountered in insulation, dissipation factor is practically the equivalent of power factor, and the terms are used interchangeably.

Low values are favorable, indicating a more efficient system, with lower power losses.

Arc Resistance

Arc resistance is a measure of an electrical breakdown condition along an insulating surface, caused by the formation of a conductive path on the surface. It is a common ASTM measurement, especially used with plastic materials because of the variations among plastics in the extent to which a surface breakdown occurs. Arc resistance is measured as the time, in seconds, required for breakdown along the surface of the material being measured. Surface breakdown (arcing or electrical tracking along the surface) is also affected by surface cleanliness and dryness.

The higher the value, the better. Higher values indicate greater resistance to breakdown along the surface due to arcing or tracking conditions.

TEMPERATURE CONVERSION TABLES AND FORMULAS

To convert from Fahrenheit to Celsius—locate temperature (°F) in center column and read °C in left column.

To convert from Celsius to Fahrenheit—locate temperature (°C) in center column and read °F in right column.

-459.4	Ta	-70	-60	Ta	0	1	Ta	69	70	Ta	139	140	Ta	290	300	Ta	1000
C		F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C
-273	-459.4		-56.1	-69	-92.2	-17.2	1	33.8	21.1	70	188.0	60.0	140	284.0	149	300	572
-268	-450		-55.6	-68	-90.4	-16.3	2	35.6	21.7	71	189.8	60.6	141	285.8	154	310	580
-262	-440		-55.0	-67	-88.6	-18.1	3	37.4	22.2	72	191.6	61.1	142	287.6	160	320	608
-257	-430		-54.4	-66	-86.8	-15.6	4	39.2	22.8	73	193.4	61.7	143	289.4	166	330	626
-251	-420		-53.9	-65	-85.0	-15.0	5	41.0	23.3	74	195.2	62.2	144	291.2	171	340	644
-246	-410		-53.3	-64	-83.2	-14.4	6	42.8	23.9	75	197.0	62.8	145	293.0	177	350	662
-240	-400		-52.8	-63	-81.4	-13.9	7	44.6	24.4	76	198.8	63.3	146	294.8	182	360	680
			-62.2	-62	-79.6	-13.3	8	46.4	25.0	77	200.6	63.9	147	296.6	188	370	698
			-61.7	-61	-77.8	-12.8	9	48.2	25.6	78	202.4	64.4	148	298.4	193	380	716
			-61.1	-60	-76.0				26.1	79	204.2	65.0	149	300.2	199	390	734
-234	-390		-50.6	-59	-74.2	-12.2	10	50.0	26.7	80	206.0	65.6	150	302.0	204	400	752
-229	-380		-50.0	-58	-72.4	-11.7	11	51.8	27.2	81	207.8	66.1	151	303.8	210	410	770
-223	-370		-49.5	-57	-70.6	-11.1	12	53.6	27.8	82	209.6	66.7	152	305.6	216	420	788
-218	-360		-48.9	-56	-68.8	-10.6	13	55.4	28.3	83	211.4	67.2	153	307.4	221	430	806
-212	-350		-48.4	-55	-67.0	-10.0	14	57.2	28.9	84	213.2	67.8	154	309.2	227	440	824
-207	-340		-47.8	-54	-65.2	-9.4	15	59.0	29.4	85	215.0	68.3	155	311.0	232	450	842
-201	-330		-47.3	-53	-63.4	-8.9	16	60.8	30.0	86	216.8	68.9	156	312.8	238	460	860
-196	-320		-46.7	-52	-61.6	-8.3	17	62.6	30.6	87	218.6	69.4	157	314.6	243	470	878
-190	-310		-46.2	-51	-59.8	-7.8	18	64.4	31.1	88	220.4	70.0	158	316.4	249	480	896
-184	-300		-45.6	-50	-58.0	-7.2	19	66.2	31.7	89	222.2	70.6	159	318.2	254	490	914
-179	-290		-45.0	-49	-56.2	-6.7	20	68.0	32.2	90	224.0	71.1	160	320.0	260	500	932
-173	-280		-44.4	-48	-54.4	-6.1	21	69.8	32.8	91	225.8	71.7	161	321.8	266	510	950
-169	-270		-43.9	-47	-52.6	-5.6	22	71.6	33.3	92	227.6	72.2	162	323.6	271	520	968
-168	-270	-459.4	-43.3	-46	-50.8	-5.0	23	73.4	33.9	93	229.4	72.8	163	325.4	277	530	986
-162	-260	-435	-42.8	-45	-49.0	-4.4	24	75.2	34.4	94	231.2	73.3	164	327.2	282	540	1004
-157	-250	-418	-42.3	-44	-47.2	-3.9	25	77.0	35.0	95	233.0	73.9	165	329.0	288	550	1022
-151	-240	-400	-41.7	-43	-45.4	-3.3	26	78.8	35.6	96	234.8	74.4	166	330.8	293	560	1040
-146	-230	-382	-41.1	-42	-43.6	-2.8	27	80.6	36.1	97	236.6	75.0	167	332.6	299	570	1058
-140	-220	-364	-40.6	-41	-41.8	-2.2	28	82.4	36.7	98	238.4	75.6	168	334.4	304	580	1076
-134	-210	-346	-40.0	-40	-40.0	-1.7	29	84.2	37.2	99	240.2	76.1	169	336.2	310	590	1094
-129	-200	-328															
-123	-190	-310	-39.4	-39	-38.2	-1.1	30	86.0	37.8	100	242.0	76.7	170	338.0	316	600	1112
-118	-180	-292	-38.8	-38	-36.4	-0.6	31	87.8	38.3	101	243.8	77.2	171	339.8	321	610	1130
-112	-170	-274	-38.3	-37	-34.6	0.0	32	89.6	38.9	102	245.6	77.8	172	341.6	327	620	1148
-107	-160	-256	-37.8	-36	-32.8	0.6	33	91.4	39.4	103	247.4	78.3	173	343.4	332	630	1166
-101	-150	-238	-37.2	-35	-31.0	1.1	34	93.2	40.0	104	249.2	78.9	174	345.2	338	640	1184
-96	-140	-220	-36.6	-34	-29.2	1.7	35	95.0	40.6	105	251.0	79.4	175	347.0	343	650	1202
-90	-130	-202	-36.1	-33	-27.4	2.2	36	96.8	41.1	106	252.8	80.0	176	348.8	349	660	1220
-84	-120	-184	-35.5	-32	-25.6	2.8	37	98.6	41.7	107	254.6	80.6	177	350.6	354	670	1238
-78	-110	-166	-35.0	-31	-23.8	3.3	38	100.4	42.2	108	256.4	81.1	178	352.4	360	680	1256
-73	-100	-148	-34.4	-30	-22.0	3.9	39	102.2	42.8	109	258.2	81.7	179	354.2	366	690	1274
-72.6	-99	-146.2	-33.9	-29	-20.2	4.4	40	104.0	43.3	110	260.0	82.2	180	356.0	371	700	1292
-72.2	-98	-144.4	-33.3	-28	-18.4	5.0	41	105.8	43.9	111	261.8	82.8	181	357.8	377	710	1310
-71.7	-97	-142.6	-32.8	-27	-16.6	5.6	42	107.6	44.4	112	263.6	83.3	182	359.6	382	720	1328
-71.1	-96	-140.8	-32.2	-26	-14.8	6.1	43	109.4	45.0	113	265.4	83.9	183	361.4	388	730	1346
-70.6	-95	-139.0	-31.7	-25	-13.0	6.7	44	111.2	45.6	114	267.2	84.4	184	363.2	393	740	1364
-70.0	-94	-137.2	-31.1	-24	-11.2	7.2	45	113.0	46.1	115	269.0	85.0	185	365.0	399	750	1382
-69.5	-93	-135.4	-30.6	-23	-9.4	7.8	46	114.8	46.7	116	270.8	85.6	186	366.8	404	760	1400
-68.9	-92	-133.6	-30.0	-22	-7.6	8.3	47	116.6	47.2	117	272.6	86.1	187	368.6	410	770	1418
-68.4	-91	-131.8	-29.5	-21	-5.8	8.9	48	118.4	47.8	118	274.4	86.7	188	370.4	416	780	1436
-67.8	-90	-130.0	-28.9	-20	-4.0	9.4	49	120.2	48.3	119	276.2	87.2	189	372.2	421	790	1454
-67.2	-89	-128.2	-28.3	-19	-2.2	10.0	50	122.0	48.9	120	278.0	87.8	190	374.0	427	800	1472
-66.6	-88	-126.4	-27.7	-18	0.4	10.6	51	123.8	49.4	121	279.8	88.3	191	375.8	432	810	1490
-66.1	-87	-124.6	-27.2	-17	1.4	11.1	52	125.6	50.0	122	281.6	88.9	192	377.6	438	820	1508
-65.5	-86	-122.8	-26.6	-16	3.2	11.7	53	127.4	50.6	123	283.4	89.4	193	379.4	443	830	1526
-65.0	-85	-121.0	-26.1	-15	5.0	12.2	54	129.2	51.1	124	285.2	90.0	194	381.2	449	840	1544
-64.4	-84	-119.2	-25.5	-14	6.8	12.8	55	131.0	51.7	125	287.0	90.6	195	383.0	454	850	1562
-63.9	-83	-117.4	-25.0	-13	8.6	13.3	56	132.8	52.2	126	288.8	91.1	196	384.8	460	860	1580
-63.3	-82	-115.6	-24.4	-12	10.4	13.9	57	134.6	52.8	127	290.6	91.7	197	386.6	466	870	1598
-62.8	-81	-113.8	-23.9	-11	12.2	14.4	58	136.4	53.3	128	292.4	92.2	198	388.4	471	880	1616
-62.2	-80	-112.0	-23.3	-10	14.0	15.0	59	138.2	53.9	129	294.2	92.8	199	390.2	477	890	1634
-61.7	-79	-110.2	-22.8	-9	15.8	15.6	60	140.0	54.4	130	296.0	93.3	200	392.0	482	900	1652
-61.1	-78	-108.4	-22.2	-8	17.6	16.1	61	141.8	55.0	131	297.8	93.9	201	393.8	488	910	1670
-60.6	-77	-106.6	-21.7	-7	19.4	16.7	62	143.6	55.6	132	299.6	94.4	202	395.6	493	920	1688
-60.0	-76	-104.8	-21.1	-6	21.2	17.2	63	145.4	56.1	133	301.4	95.0	203	397.4	499	930	1706
-59.6	-75	-103.0	-20.6	-5	23.0	17.8	64	147.2	56.7	134	303.2	95.6	204	399.2	504	940	1724
-59.0	-74	-101.2	-20.0	-4	24.8	18.3	65	149.0	57.2	135	305.0	96.1	205	401.0	510	950	1742
-58.4	-73	-99.4	-19.5	-3	26.6	18.9	66	150.8	57.8	136	306.8	96.7	206	402.8	516	960	1760
-57.8	-72	-97.6	-18.9	-2	28.4	19.4	67	152.6	58.3	137	308.6	97.2	207	404.6	521	970	1778
-57.3	-71	-95.8	-18.4	-1	30.2	20.0	68	154.4	58.9	138	310.4	97.8	208	406.4	527	980	1796
-56.7	-70	-94.0	-17.8	0	32.0	20.6	69	156.2	59.4	139	312.2	98.3	209	408.2	532	990	1814
												143	290	564			

1000 to 1490		1500 to 1990		2000 to 2490		2500 to 3000	
C	F	C	F	C	F	C	F
538	1000 1832	816	1500 2732	1093	2000 3632	1371	2500 4532
543	1010 1850	821	1510 2750	1099	2010 3650	1377	2510 4550
549	1020 1868	827	1520 2768	1104	2020 3668	1382	2520 4568
554	1030 1886	832	1530 2786	1110	2030 3686	1388	2530 4586
560	1040 1904	838	1540 2804	1116	2040 3704	1393	2540 4604
566	1050 1922	843	1550 2822	1121	2050 3722	1399	2550 4622
571	1060 1940	849	1560 2840	1127	2060 3740	1404	2560 4640
577	1070 1958	854	1570 2858	1132	2070 3758	1410	2570 4658
582	1080 1976	860	1580 2876	1138	2080 3776	1416	2580 4676
588	1090 1994	866	1590 2894	1143	2090 3794	1421	2590 4694
593	1100 2012	871	1600 2912	1149	2100 3812	1427	2600 4712
599	1110 2030	877	1610 2930	1154	2110 3830	1432	2610 4730
604	1120 2048	882	1620 2948	1160	2120 3848	1438	2620 4748
610	1130 2066	888	1630 2966	1166	2130 3866	1443	2630 4765
616	1140 2084	893	1640 2984	1171	2140 3884	1449	2640 4784
621	1150 2102	899	1650 3002	1177	2150 3902	1454	2650 4802
627	1160 2120	904	1660 3020	1182	2160 3920	1460	2660 4820
632	1170 2138	910	1670 3038	1188	2170 3938	1466	2670 4838
638	1180 2156	916	1680 3056	1193	2180 3956	1471	2680 4856
643	1190 2174	921	1690 3074	1199	2190 3974	1477	2690 4874
649	1200 2192	927	1700 3092	1204	2200 3992	1482	2700 4892
654	1210 2210	932	1710 3110	1210	2210 4010	1488	2710 4910
660	1220 2228	938	1720 3128	1216	2220 4028	1493	2720 4928
666	1230 2246	943	1730 3146	1221	2230 4046	1499	2730 4945
671	1240 2264	949	1740 3164	1227	2240 4064	1504	2740 4964
677	1250 2282	954	1750 3182	1232	2250 4082	1510	2750 4982
682	1260 2300	960	1760 3200	1238	2260 4100	1516	2760 5000
688	1270 2318	966	1770 3218	1243	2270 4118	1521	2770 5018
693	1280 2336	971	1780 3236	1249	2280 4136	1527	2780 5036
699	1290 2354	977	1790 3254	1254	2290 4154	1532	2790 5054
704	1300 2372	982	1800 3272	1260	2300 4172	1538	2800 5072
710	1310 2390	988	1810 3290	1266	2310 4190	1543	2810 5090
716	1320 2408	993	1820 3308	1271	2320 4208	1549	2820 5108
721	1330 2426	999	1830 3326	1277	2330 4226	1554	2830 5126
727	1340 2444	1004	1840 3344	1282	2340 4244	1560	2840 5144
732	1350 2462	1010	1850 3362	1288	2350 4262	1566	2850 5162
738	1360 2480	1016	1860 3380	1293	2360 4280	1571	2860 5180
743	1370 2498	1021	1870 3398	1299	2370 4298	1577	2870 5198
749	1380 2516	1027	1880 3416	1304	2380 4316	1582	2880 5216
754	1390 2534	1032	1890 3434	1310	2390 4334	1588	2890 5234
760	1400 2552	1038	1900 3452	1316	2400 4352	1593	2900 5252
766	1410 2570	1043	1910 3470	1321	2410 4370	1599	2910 5270
771	1420 2588	1049	1920 3488	1327	2420 4388	1604	2920 5288
777	1430 2606	1054	1930 3506	1332	2430 4406	1610	2930 5306
782	1440 2624	1060	1940 3524	1338	2440 4424	1616	2940 5324
788	1450 2642	1066	1950 3542	1343	2450 4442	1621	2950 5342
793	1460 2660	1071	1960 3560	1349	2460 4460	1627	2960 5360
799	1470 2678	1077	1970 3578	1354	2470 4478	1632	2970 5378
804	1480 2696	1082	1980 3596	1360	2480 4496	1638	2980 5396
810	1490 2714	1088	1990 3614	1366	2490 4514	1643	2990 5414
						1649	3000 5432

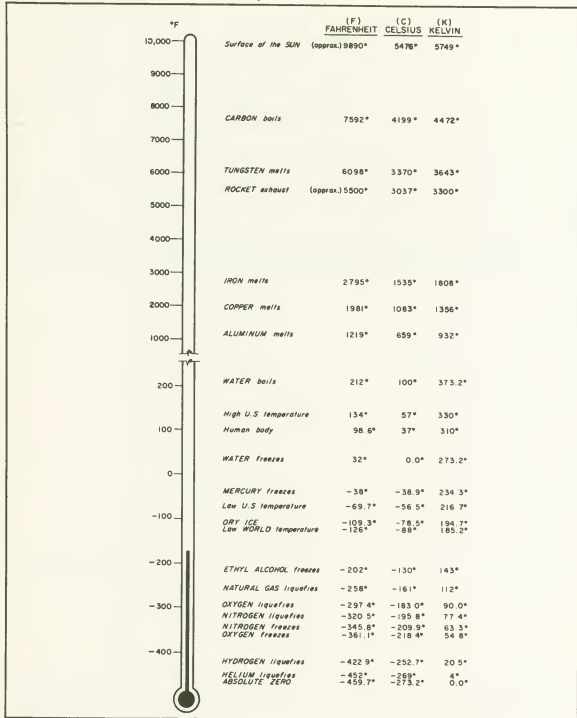
Interpolation Factors			Interpolation Factors		
C		F	C		F
0.56	1	1.8	3.33	6	10.8
1.11	2	3.6	3.89	7	12.6
1.67	3	5.4	4.44	8	14.4
2.22	4	7.2	5.00	9	16.2
2.78	5	9.0	5.56	10	18.0

*The term Centigrade was officially changed to Celsius by international agreement in 1948. The Celsius scale uses the triple phase point of water, at 0° Centigrade, in place of the ice point as a reference, but for all practical purposes the two terms are interchangeable.

Given	Temperature Conversion				
	Celsius	Fahrenheit	Kelvin	Reaumur	Rankine
Cels.	—	$\left(\frac{9}{5}C\right) + 32$	$C + 273.16$	$\frac{4}{5}C$	$1.8(C + 273.16)$
Fahr.	$\frac{5}{9}(F - 32)$	—	$\left[\frac{5}{9}(F - 32)\right] + 273.16$	$\frac{4}{9}(F - 32)$	$F + 459.7$
Kelvin	$K - 273.16$	$\left[\frac{9}{5}(K - 273.16)\right] + 32$	—	$\frac{4}{5}(K - 273.16)$	$K \times 1.8$
Reau.	$Re \times \frac{5}{4}$	$\left(\frac{9}{4}Re\right) + 32$	$\left(\frac{5}{4}Re\right) + 273.16$	—	$\left(\frac{9}{4}Re\right) + 491.7$
Rank.	$\frac{Ra}{1.8} - 273.16$	$Ra - 459.7$	$\frac{Ra}{1.8}$	$\frac{4}{9}(Ra - 491.7)$	—

Five major temperature scales are in use at present. They are: Fahrenheit, Celsius, Kelvin (Absolute), Rankine, and Reaumur. The interrelationship among the scales is shown here.

Comparative Temperature Scales



RELATIVE HUMIDITY TABLES

DIFFERENCE IN DEGREES FAHRENHEIT BETWEEN WET AND DRY BULB THERMOMETERS.

DRY Bulb Temperature Fahrenheit	Difference in Degrees Fahrenheit Between Wet and Dry Bulb Thermometers										DRY Bulb Temperature Fahrenheit
	1	2	3	4	5	6	7	8	9	10	
184	88	64	48	36	28	20	14	10	8	6	184
185	89	65	49	37	29	21	15	11	9	7	185
186	90	66	50	38	30	22	16	12	10	8	186
187	91	67	51	39	31	23	17	13	11	9	187
188	92	68	52	40	32	24	18	14	12	10	188
189	93	69	53	41	33	25	19	15	13	11	189
190	94	70	54	42	34	26	20	16	14	12	190
191	95	71	55	43	35	27	21	17	15	13	191
192	96	72	56	44	36	28	22	18	16	14	192
193	97	73	57	45	37	29	23	19	17	15	193
194	98	74	58	46	38	30	24	20	18	16	194
195	99	75	59	47	39	31	25	21	19	17	195
196	100	76	60	48	40	32	26	22	20	18	196
197	101	77	61	49	41	33	27	23	21	19	197
198	102	78	62	50	42	34	28	24	22	20	198
199	103	79	63	51	43	35	29	25	23	21	199
200	104	80	64	52	44	36	30	26	24	22	200
201	105	81	65	53	45	37	31	27	25	23	201
202	106	82	66	54	46	38	32	28	26	24	202
203	107	83	67	55	47	39	33	29	27	25	203
204	108	84	68	56	48	40	34	30	28	26	204
205	109	85	69	57	49	41	35	31	29	27	205
206	110	86	70	58	50	42	36	32	30	28	206
207	111	87	71	59	51	43	37	33	31	29	207
208	112	88	72	60	52	44	38	34	32	30	208
209	113	89	73	61	53	45	39	35	33	31	209
210	114	90	74	62	54	46	40	36	34	32	210
211	115	91	75	63	55	47	41	37	35	33	211
212	116	92	76	64	56	48	42	38	36	34	212
213	117	93	77	65	57	49	43	39	37	35	213
214	118	94	78	66	58	50	44	40	38	36	214
215	119	95	79	67	59	51	45	41	39	37	215
216	120	96	80	68	60	52	46	42	40	38	216
217	121	97	81	69	61	53	47	43	41	39	217
218	122	98	82	70	62	54	48	44	42	40	218
219	123	99	83	71	63	55	49	45	43	41	219
220	124	100	84	72	64	56	50	46	44	42	220
221	125	101	85	73	65	57	51	47	45	43	221
222	126	102	86	74	66	58	52	48	46	44	222
223	127	103	87	75	67	59	53	49	47	45	223
224	128	104	88	76	68	60	54	50	48	46	224
225	129	105	89	77	69	61	55	51	49	47	225
226	130	106	90	78	70	62	56	52	50	48	226
227	131	107	91	79	71	63	57	53	51	49	227
228	132	108	92	80	72	64	58	54	52	50	228
229	133	109	93	81	73	65	59	55	53	51	229
230	134	110	94	82	74	66	60	56	54	52	230
231	135	111	95	83	75	67	61	57	55	53	231
232	136	112	96	84	76	68	62	58	56	54	232
233	137	113	97	85	77	69	63	59	57	55	233
234	138	114	98	86	78	70	64	60	58	56	234
235	139	115	99	87	79	71	65	61	59	57	235
236	140	116	100	88	80	72	66	62	60	58	236
237	141	117	101	89	81	73	67	63	61	59	237
238	142	118	102	90	82	74	68	64	62	60	238
239	143	119	103	91	83	75	69	65	63	61	239
240	144	120	104	92	84	76	70	66	64	62	240
241	145	121	105	93	85	77	71	67	65	63	241
242	146	122	106	94	86	78	72	68	66	64	242
243	147	123	107	95	87	79	73	69	67	65	243
244	148	124	108	96	88	80	74	70	68	66	244
245	149	125	109	97	89	81	75	71	69	67	245
246	150	126	110	98	90	82	76	72	70	68	246
247	151	127	111	99	91	83	77	73	71	69	247
248	152	128	112	100	92	84	78	74	72	70	248
249	153	129	113	101	93	85	79	75	73	71	249
250	154	130	114	102	94	86	80	76	74	72	250
251	155	131	115	103	95	87	81	77	75	73	251
252	156	132	116	104	96	88	82	78	76	74	252
253	157	133	117	105	97	89	83	79	77	75	253
254	158	134	118	106	98	90	84	80	78	76	254
255	159	135	119	107	99	91	85	81	79	77	255
256	160	136	120	108	100	92	86	82	80	78	256
257	161	137	121	109	101	93	87	83	81	79	257
258	162	138	122	110	102	94	88	84	82	80	258
259	163	139	123	111	103	95	89	85	83	81	259
260	164	140	124	112	104	96	90	86	84	82	260
261	165	141	125	113	105	97	91	87	85	83	261
262	166	142	126	114	106	98	92	88	86	84	262
263	167	143	127	115	107	99	93	89	87	85	263
264	168	144	128	116	108	100	94	90	88	86	264
265	169	145	129	117	109	101	95	91	89	87	265
266	170	146	130	118	110	102	96	92	90	88	266
267	171	147	131	119	111	103	97	93	91	89	267
268	172	148	132	120	112	104	98	94	92	90	268
269	173	149	133	121	113	105	99	95	93	91	269
270	174	150	134	122	114	106	100	96	94	92	270
271	175	151	135	123	115	107	101	97	95	93	271
272	176	152	136	124	116	108	102	98	96	94	272
273	177	153	137	125	117	109	103	99	97	95	273
274	178	154	138	126	118	110	104	100	98	96	274
275	179	155	139	127	119	111	105	101	99	97	275
276	180	156	140	128	120	112	106	102	100	98	276
277	181	157	141	129	121	113	107	103	101	99	277
278	182	158	142	130	122	114	108	104	102	100	278
279	183	159	143	131	123	115	109	105	103	101	279
280	184	160	144	132	124	116	110	106	104	102	280
281	185	161	145	133	125	117	111	107	105	103	281
282	186	162	146	134	126	118	112	108	106	104	282
283	187	163	147	135	127	119	113	109	107	105	283
284	188	164	148	136	128	120	114	110	108	106	284
285	189	165	149	137	129	121	115	111	109	107	285
286	190	166	150	138	130	122	116	112	110	108	286
287	191	167	151	139	131	123	117	113	111	109	287
288	192	168	152	140	132	124	118	114	112	110	288
289	193	169	153	141	133	125	119	115	113	111	289
290	194	170	154	142	134	126	120	116	114	112	290
291	195	171	155	143	135	127	121	117	115	113	291
292	196	172	156	144	136	128	122	118	116	114	292
293	197	173	157	145	137	129	123	119	117	115	293
294	198	174	158	146	138	130	124	120	118	116	294
295	199	175	159	147	139	131	125	121	119	117	295
296	200	176	160	148	140	132	126	122	120	118	296
297	201	177	161	149	141	133	127	123	121	119	297
298	202	178	162	150	142	134	128	124	122	120	298
299	203	179	163	151	143	135	129	125	123	121	299
300	204	180	164	152	144	136	130	126	124	122	300

DBT TEMP. °C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
50	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288	300	312	324	336	348	360	372	384	396	408	420	432	444	456	468	480	492	504	516	528	540	552	564	576	588	600	612	624	636	648	660	672	684	696	708	720	732	744	756	768	780	792	804	816	828	840	852	864	876	888	900	912	924	936	948	960	972	984	996	1008	1020	1032	1044	1056	1068	1080	1092	1104	1116	1128	1140	1152	1164	1176	1188	1200	1212	1224	1236	1248	1260	1272	1284	1296	1308	1320	1332	1344	1356	1368	1380	1392	1404	1416	1428	1440	1452	1464	1476	1488	1500	1512	1524	1536	1548	1560	1572	1584	1596	1608	1620	1632	1644	1656	1668	1680	1692	1704	1716	1728	1740	1752	1764	1776	1788	1800	1812	1824	1836	1848	1860	1872	1884	1896	1908	1920	1932	1944	1956	1968	1980	1992	2004	2016	2028	2040	2052	2064	2076	2088	2100	2112	2124	2136	2148	2160	2172	2184	2196	2208	2220	2232	2244	2256	2268	2280	2292	2304	2316	2328	2340	2352	2364	2376	2388	2400	2412	2424	2436	2448	2460	2472	2484	2496	2508	2520	2532	2544	2556	2568	2580	2592	2604	2616	2628	2640	2652	2664	2676	2688	2700	2712	2724	2736	2748	2760	2772	2784	2796	2808	2820	2832	2844	2856	2868	2880	2892	2904	2916	2928	2940	2952	2964	2976	2988	3000	3012	3024	3036	3048	3060	3072	3084	3096	3108	3120	3132	3144	3156	3168	3180	3192	3204	3216	3228	3240	3252	3264	3276	3288	3300	3312	3324	3336	3348	3360	3372	3384	3396	3408	3420	3432	3444	3456	3468	3480	3492	3504	3516	3528	3540	3552	3564	3576	3588	3600	3612	3624	3636	3648	3660	3672	3684	3696	3708	3720	3732	3744	3756	3768	3780	3792	3804	3816	3828	3840	3852	3864	3876	3888	3900	3912	3924	3936	3948	3960	3972	3984	3996	4008	4020	4032	4044	4056	4068	4080	4092	4104	4116	4128	4140	4152	4164	4176	4188	4200	4212	4224	4236	4248	4260	4272	4284	4296	4308	4320	4332	4344	4356	4368	4380	4392	4404	4416	4428	4440	4452	4464	4476	4488	4500	4512	4524	4536	4548	4560	4572	4584	4596	4608	4620	4632	4644	4656	4668	4680	4692	4704	4716	4728	4740	4752	4764	4776	4788	4800	4812	4824	4836	4848	4860	4872	4884	4896	4908	4920	4932	4944	4956	4968	4980	4992	5004	5016	5028	5040	5052	5064	5076	5088	5100	5112	5124	5136	5148	5160	5172	5184	5196	5208	5220	5232	5244	5256	5268	5280	5292	5304	5316	5328	5340	5352	5364	5376	5388	5400	5412	5424	5436	5448	5460	5472	5484	5496	5508	5520	5532	5544	5556	5568	5580	5592	5604	5616	5628	5640	5652	5664	5676	5688	5700	5712	5724	5736	5748	5760	5772	5784	5796	5808	5820	5832	5844	5856	5868	5880	5892	5904	5916	5928	5940	5952	5964	5976	5988	6000	6012	6024	6036	6048	6060	6072	6084	6096	6108	6120	6132	6144	6156	6168	6180	6192	6204	6216	6228	6240	6252	6264	6276	6288	6300	6312	6324	6336	6348	6360	6372	6384	6396	6408	6420	6432	6444	6456	6468	6480	6492	6504	6516	6528	6540	6552	6564	6576	6588	6600	6612	6624	6636	6648	6660	6672	6684	6696	6708	6720	6732	6744	6756	6768	6780	6792	6804	6816	6828	6840	6852	6864	6876	6888	6900	6912	6924	6936	6948	6960	6972	6984	6996	7008	7020	7032	7044	7056	7068	7080	7092	7104	7116	7128	7140	7152	7164	7176	7188	7200	7212	7224	7236	7248	7260	7272	7284	7296	7308	7320	7332	7344	7356	7368	7380	7392	7404	7416	7428	7440	7452	7464	7476	7488	7500	7512	7524	7536	7548	7560	7572	7584	7596	7608	7620	7632	7644	7656	7668	7680	7692	7704	7716	7728	7740	7752	7764	7776	7788	7800	7812	7824	7836	7848	7860	7872	7884	7896	7908	7920	7932	7944	7956	7968	7980	7992	8004	8016	8028	8040	8052	8064	8076	8088	8100	8112	8124	8136	8148	8160	8172	8184	8196	8208	8220	8232	8244	8256	8268	8280	8292	8304	8316	8328	8340	8352	8364	8376	8388	8400	8412	8424	8436	8448	8460	8472	8484	8496	8508	8520	8532	8544	8556	8568	8580	8592	8604	8616	8628	8640	8652	8664	8676	8688	8700	8712	8724	8736	8748	8760	8772	8784	8796	8808	8820	8832	8844	8856	8868	8880	8892	8904	8916	8928	8940	8952	8964	8976	8988	9000	9012	9024	9036	9048	9060	9072	9084	9096	9108	9120	9132	9144	9156	9168	9180	9192	9204	9216	9228	9240	9252	9264	9276	9288	9300	9312	9324	9336	9348	9360	9372	9384	9396	9408	9420	9432	9444	9456	9468	9480	9492	9504	9516	9528	9540	9552	9564	9576	9588	9600	9612	9624	9636	9648	9660	9672	9684	9696	9708	9720	9732	9744	9756	9768	9780	9792	9804	9816	9828	9840	9852	9864	9876	9888	9900	9912	9924	9936	9948	9960	9972	9984	9996	10008	10020	10032	10044	10056	10068	10080	10092	10104	10116	10128	10140	10152	10164	10176	10188	10200	10212	10224	10236	10248	10260	10272	10284	10296	10308	10320	10332	10344	10356	10368	10380	10392	10404	10416	10428	10440	10452	10464	10476	10488	10500	10512	10524	10536	10548	10560	10572	10584	10596	10608	10620	10632	10644	10656	10668	10680	10692	10704	10716	10728	10740	10752	10764	10776	10788	10800	10812	10824	10836	10848	10860	10872	10884	10896	10908	10920	10932	10944	10956	10968	10980	10992	11004	11016	11028	11040	11052	11064	11076	11088	11100	11112	11124	11136	11148	11160	11172	11184	11196	11208	11220	11232	11244	11256	11268	11280	11292	11304	11316	11328	11340	11352	11364	11376	11388	11400	11412	11424	11436	11448	11460	11472	11484	11496	11508	11520	11532	11544	11556	11568	11580	11592	11604	11616	11628	11640	11652	11664	11676	11688	11700	11712	11724	11736	11748	11760	11772	11784	11796	11808	11820	11832	11844	11856	11868	11880	11892	11904	11916	11928	11940	11952	11964	11976	11988	12000	12012	12024	12036	12048	12060	12072	12084	12096	12108	12120	12132	12144	12156	12168	12180	12192	12204	12216	12228	12240	12252	12264	12276	12288	12300	12312	12324	12336	12348	12360	12372	12384	12396	12408	12420	12432	12444	12456	12468	12480	12492	12504	12516	12528	12540	12552	12564	12576	12588	12600	12612	12624	12636	12648	12660	12672	12684	12696	12708	12720	12732	12744	12756	12768	12780	12792	12804	12816	12828	12840	12852	12864	12876	12888	12900	12912	12924	12936	12948	12960	12972	12984	12996	13008	13020	13032	13044	13056	13068	13080	13092	13104	13116	13128	13140	13152	13164	13176	13188	13200	13212	13224	13236	13248	13260	13272	13284	13296	13308	13320	13332	13344	13356	13368	13380	13392	13404	13416	13428	13440	13452	13464	13476	13488	13500	13512	13524	13536	13548	13560	13572	13584	13596	13608	13620	13632	13644	13656	13668	13680	13692	13704	13716	13728	13740	13752	13764	13776	13788	13800	13812	13824	13836	13848	13860	13872	13884	13896	13908	13920	13932	13944	13956	13968	13980	13992	14004	14016	14028	14040	14052	14064	14076	14088	14100	14112	14124	14136	14148	14160	14172	14184	14196	14208	14220	14232	14244	14256	14268	14280	14292	14304	14316	14328	14340	14352	14364	14376	14388	14400	14412	14424	14436	14448	14460	14472	14484	14496	14508	14520	14532	14544	14556	14568	14580	14592	14604	14616	14628	14640	14652	14664	14676	14688	14700	14712	14724	14736	14748	14760	14772	14784	14796	14808	14820	14832	14844	14856	14868	14880	14892	14904	14916	14928	14940	14952	14964	14976	14988	15000	15012	15024	15036	15048	15060	15072	15084	15096	15108	15120	15132	15144	15156	15168	15180	15192	15204	15216	15228	15240	15252	15264	15276	15288	15300	15312	15324	15336	15348	15360	15372	15384	15396	15408	15420	15432	15444	15456	15468	15480	15492	15504	15516	15528	15540	15552	15564	15576	15588	1

TEMPERATURE-HUMIDITY INDEX

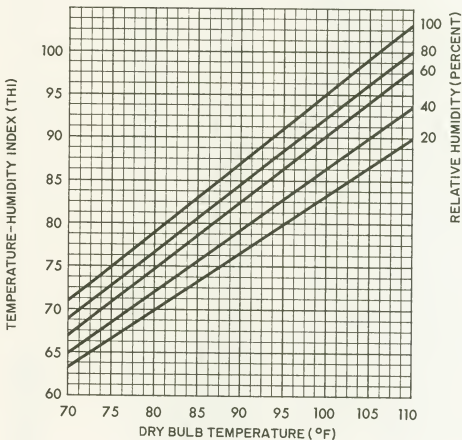
The United States Weather Bureau developed the formula for temperature—humidity index. It is based on temperature and relative humidity.

$$THI = 15 + 0.4(T_{\text{dry bulb}} + T_{\text{wet bulb}})$$

where temperatures are in degrees Fahrenheit. It has been determined that when the THI reaches 72, some people are uncomfortable; when it reaches 76 most everyone is uncomfortable.

Actually it is the combination of both high temperature and high humidity which causes discomfort. Lowering either one will increase comfort. On the other hand, lower temperature plus low humidity can cause discomfort on the cool side. Thus, in the wintertime, when the humidity in heated buildings is low, a higher temperature is needed for comfort than is required during other seasons when the humidity is higher.

FOR EXAMPLE: At a dry-bulb temperature of 75°F and a relative humidity of 60%, the THI is 71.

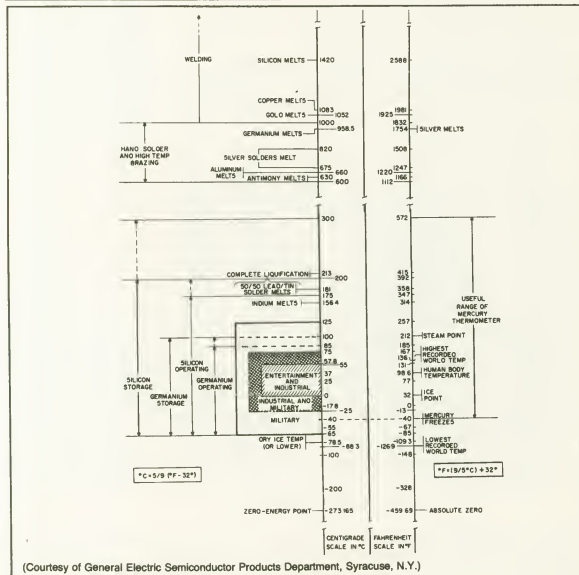


COLOR SCALE OF TEMPERATURE

Commonly used terms to describe the color of heat are related to the approximate range of temperature.

Incipient red heat	500- 550	Yellow heat	1050-1150
Dark red heat	650- 750	Incipient white heat	1250-1350
Bright red heat	800- 900	White heat	Above 1450
Orange-red heat	900-1000		

THERMAL SPECTRUM



(Courtesy of General Electric Semiconductor Products Department, Syracuse, N.Y.)

STANDARD ANNEALED COPPER WIRE TABLE

AWG B & S Gauge	Diam- eter in Mils	Cross Section		Ohms/ 1000 Ft at 20°C (68°F)	Lb/ 1000 Ft	Ft/Lb	Ft/Ohm at 20°C (68°F)	Ohms/Lb at 20°C (68°F)	Lb/Ohm at 20°C (68°F)
		Circular Mils	Square Inches						
0000	460.0	211,600	0.1662	0.04901	640.5	1.561	20,400	0.0007652	13,070
000	409.6	167,800	0.1318	0.06180	507.9	1.968	16,180	0.0001217	8,219
00	364.8	133,100	0.1045	0.07793	402.8	2.482	12,830	0.0001935	5,169
0	324.9	105,500	0.08289	0.09827	319.5	3.130	10,180	0.0003076	3,251
1	289.3	83,690	0.06573	0.1239	253.3	3.947	8,070	0.0004891	2,044
2	257.6	66,370	0.05213	0.1563	200.9	4.977	6,400	0.0007778	1,286
3	229.4	52,640	0.04134	0.1970	159.3	6.276	5,075	0.001237	808.6
4	204.3	41,740	0.03278	0.2485	126.4	7.914	4,025	0.001966	508.5
5	181.9	33,100	0.02600	0.3133	100.2	9.980	3,192	0.003127	319.8
6	162.0	26,250	0.02062	0.3951	79.46	12.58	2,531	0.004972	201.1
7	144.3	20,820	0.01635	0.4982	63.02	15.87	2,007	0.007905	126.5
8	128.5	16,510	0.01297	0.6282	49.98	20.01	1,592	0.01257	79.55
9	114.4	13,090	0.01028	0.7921	39.63	25.23	1,262	0.01999	50.03
10	101.9	10,380	0.008155	0.9989	31.43	31.82	1,001	0.03178	31.47
11	90.74	8,234	0.006467	1.260	24.92	40.12	794	0.05053	19.79
12	80.81	6,530	0.005129	1.588	19.77	50.59	629	0.08035	12.45
13	71.96	5,178	0.004067	2.003	15.68	63.80	499.3	0.1278	7.827
14	64.08	4,107	0.003225	2.525	12.43	80.44	396.0	0.2032	4.922
15	57.07	3,257	0.002558	3.184	9.858	101.4	314.0	0.3230	3.096
16	50.82	2,583	0.002028	4.016	7.818	127.9	249.0	0.5136	1.947
17	45.26	2,048	0.001609	5.064	6.200	161.3	197.5	0.8167	1.224
18	40.30	1,624	0.001276	6.385	4.917	203.4	156.6	1.299	0.7700
19	35.89	1,288	0.001012	8.051	3.899	256.5	124.2	2.065	0.4843
20	31.96	1,022	0.0008023	10.15	3.092	323.4	98.50	3.283	0.3046
21	28.46	810.1	0.0006363	12.80	2.452	407.8	78.11	5.221	0.1915
22	25.35	642.4	0.0005046	16.14	1.945	514.2	61.95	8.301	0.1205
23	22.57	509.5	0.0004002	20.36	1.542	648.4	49.13	13.20	0.07576
24	20.10	404.0	0.0003173	25.67	1.223	817.7	38.96	20.99	0.04765
25	17.90	320.4	0.0002517	32.37	0.9699	1,031.0	30.90	33.37	0.02997
26	15.94	254.1	0.0001996	40.81	0.7692	1,300	24.50	53.06	0.01885
27	14.20	201.5	0.0001583	51.47	0.6100	1,639	19.43	84.37	0.01185
28	12.64	159.8	0.0001255	64.90	0.4837	2,067	15.41	134.2	0.007454
29	11.26	126.7	0.00009953	81.83	0.3836	2,607	12.22	213.3	0.004688
30	10.03	100.5	0.00007894	103.2	0.3042	3,287	9.691	339.2	0.002948
31	8.928	79.70	0.00006260	130.1	0.2413	4,145	7.685	539.3	0.001854
32	7.950	63.21	0.00004964	164.1	0.1913	5,227	6.095	857.6	0.001166
33	7.080	50.13	0.00003937	206.9	0.1517	6,591	4.833	1,364	0.0007333
34	6.305	39.75	0.00003122	260.9	0.1203	8,310	3.833	2,168	0.0004612
35	5.615	31.52	0.00002476	329.0	0.09542	10,480	3.040	3,448	0.0002901
36	5.000	25.00	0.00001964	414.8	0.07568	13,210	2.411	5,482	0.0001824
37	4.453	19.83	0.00001557	523.1	0.06001	16,660	1.912	8,717	0.0001147
38	3.965	15.72	0.00001235	659.6	0.04759	21,010	1.516	13,860	0.00007215
39	3.531	12.47	0.000009793	831.8	0.03774	26,500	1.202	22,040	0.00004538
40	3.145	9.888	0.000007766	1049.0	0.02993	33,410	0.9534	35,040	0.00002854

Temperature coefficient of resistance: The resistance of a conductor at temperature t in degrees Celsius is given by

$$R_t = R_{20} [1 + a_{20} (t - 20)]$$

where R_{20} is the resistance at 20°C and a_{20} is the temperature coefficient of resistance at 20°C. For copper, $a_{20} = 0.00393$. That is, the resistance of a copper conductor increases approximately 0.4% per degree Celsius rise in temperature.

PROPERTIES OF COMMON WIRE AND CABLE INSULATIONS

Insulation Material	Breakdown Voltage	R. F. Losses	Operating Temp. (°C)	Weather Resistance	Flexibility	Suggested Use
Standard PVC	High	Medium	-20 to +80	Good	Fair	General purpose
Premium PVC	High	Medium	-55 to +105	Good	Fair	General purpose
Polyethylene	High	Low	-60 to +80	Good	Good	R. f. cables
Natural rubber	High	High	-40 to +70	Poor	Good	Light duty
Neoprene	Low	High	-30 to +90	Good	Good	Rough service
Waxed cotton	Low	High		Poor	Good	Experimenting
Teflon	High	Low	-70 to +260	Good	Fair	High temperature

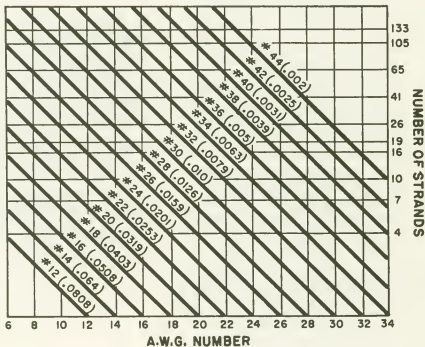
WIRE STRANDING CHART

A stranded conductor is made up of a number of smaller wire strands. This chart shows the size of each strand, when the number of strands in the finished wire size is known. Also, the number of strands for each given strand size may be determined for a finished wire gauge size.

Locate the conductor's desired AWG size on the chart and trace it vertically. The number and size of strands needed to make the stranded conductor will be indicated by the horizontal line (strand number) and diagonal line (strand size), respectively.

For example:

A #22 AWG stranded conductor can be made with 4 strands of #28 AWG wire or 10 strands of #32 AWG wire, etc.



TEMPERATURE CLASSIFICATION OF INSULATING MATERIALS

Temperature Classifications

Definitions of Insulating Materials (IEEE)

Class	Definition	
0	Materials or combinations of materials such as cotton, silk, and paper without impregnation. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at	90C
A	Materials or combinations of materials such as cotton, silk, and paper when suitably impregnated or coated or when immersed in a dielectric liquid such as oil. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at	105C
B	Materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable bonding substances. Other materials or combinations of materials, not necessarily inorganic, may be included in this class if by experience or accepted tests they can be shown to be capable of operation at	130C
F	Materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable bonding substances. Other materials or combinations of materials, not necessarily inorganic, may be included in this class if by experience or accepted tests they can be shown to be capable of operation at	155C
H	Materials or combinations of materials such as silicone elastomer, mica, glass fiber, asbestos, etc., with suitable bonding substances such as appropriate silicone resins. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at	180C
220C	Materials or combinations of materials which by experience or accepted tests can be shown to be capable of operation at	220C
Over 220C (class C)	Insulation that consists entirely of mica, porcelain, glass, quartz, and similar inorganic materials. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at temperatures over	220C

NOTES:

1. Insulation is considered to be "impregnated" when a suitable substance provides a bond between components of the structure and also a degree of filling and surface coverage sufficient to give adequate performance under the extremes of temperature, surface contamination (moisture, dirt, etc.), and mechanical stress expected in service. The impregnant must not flow or deteriorate enough at operating temperature so as to seriously affect performance in service.
2. The electrical and mechanical properties of the insulation must not be impaired by the prolonged application of the limiting insulation temperature permitted for the specific insulation class. The word "impaired" is here used in the sense of causing any change which could disqualify the insulating material for continuously performing its intended function whether creepage spacing, mechanical support, or dielectric barrier action.
3. In the above definitions the words "accepted tests" are intended to refer to recognized Test Procedures established for the thermal evaluation of materials by themselves or in simple combinations. Experience or test data, used in classifying insulating materials are distinct from the experience or test data derived for the use of materials in complete insulation systems. The thermal endurance of complete systems may be determined by Test Procedures specified by the responsible Technical Committees. A material that is classified as suitable for a given temperature may be found suitable for a different temperature, either higher or lower, by an insulation system Test Procedure. For example, it has been found that some materials suitable for operation at one temperature in air may be suitable for a higher temperature when used in a system operated in an inert gas atmosphere.
4. It is important to recognize that other characteristics, in addition to thermal endurance, such as mechanical strength, moisture resistance and corona endurance, are required in varying degrees in different applications for the successful use of insulating materials.

VOLTAGE-CURRENT-WIRE SIZE NOMOGRAM

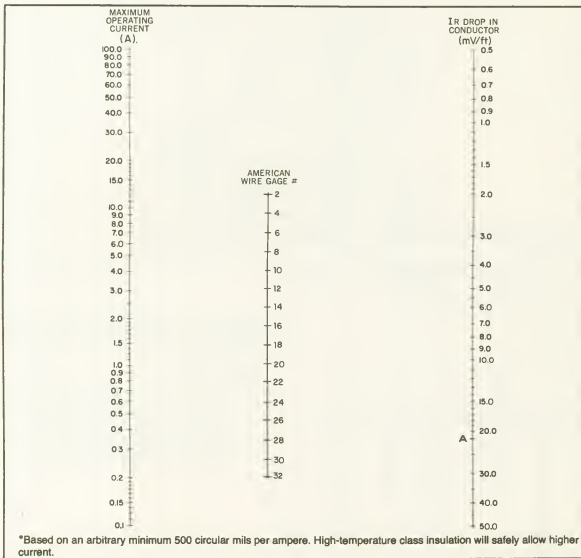
This nomogram can be used to determine:

1. The minimum wire size for any given load current and voltage drop;
2. the mV drop/foot for any given wire size and load current;
3. the maximum recommended* current for any given size wire.

FOR EXAMPLE: 1. With a permissible voltage drop of 5 mV /ft, the minimum wire size in a 3-A circuit is #12 AWG.

2. At 300 mA the voltage drop across #22 AWG wire is 4.5 mV /ft.

3. The maximum recommended current for #18 AWG wire is 3.5 A. (This is found by connecting point A on the IR drop scale with the wire gauge scale, and reading the intersect point on the Current scale).



FUSING CURRENTS OF WIRES

This table gives the fusing currents in amperes for five commonly used types of wires. The current I in amperes at which a wire will melt can be calculated from $I = Kd^{3/2}$ where d is the wire diameter in inches and K is a constant that depends on the metal concerned. A wide variety of factors influence the rate of heat loss, and these figures must be considered approximations.

AWG & S Gauge	d (in.)	Copper $K = 10,244$	Alu- minum $K = 7585$	German Silver $K = 5230$	Iron $K = 3148$	Tin $K = 1642$
40	0.0031	1.77	1.31	0.90	0.54	0.28
38	0.0039	2.50	1.85	1.27	0.77	0.40
36	0.0050	3.62	2.68	1.85	1.11	0.58
34	0.0063	5.12	3.79	2.61	1.57	0.82
32	0.0079	7.19	5.32	3.67	2.21	1.15
30	0.0100	10.2	7.58	5.23	3.15	1.64
28	0.0126	14.4	10.7	7.39	4.45	2.32
26	0.0159	20.5	15.2	10.5	6.31	3.29
24	0.0201	29.2	21.6	14.9	8.97	4.68
22	0.0253	41.2	30.5	21.0	12.7	6.61
20	0.0319	58.4	43.2	29.8	17.9	9.36
19	0.0359	68.7	51.6	35.5	21.4	11.2
18	0.0403	82.9	61.4	42.3	25.5	13.3
17	0.0452	98.4	72.9	50.2	30.2	15.8
16	0.0508	117	86.8	59.9	36.0	18.8
15	0.0571	140	103	71.4	43.0	22.4
14	0.0641	166	123	84.9	51.1	26.6
13	0.0719	197	146	101	60.7	31.7
12	0.0808	235	174	120	72.3	37.7
11	0.0907	280	207	143	86.0	44.9
10	0.1019	333	247	170	102	53.4
9	0.1144	396	293	202	122	63.5
8	0.1285	472	349	241	145	75.6
7	0.1443	561	416	287	173	90.0
6	0.1620	668	495	341	205	107

SUGGESTED AMPACITIES FOR APPLIANCE WIRING MATERIAL—ALL TYPES OF INSULATION

Copper Temperature					
Size AWG	90C	105C	125C	200C	250C
Amperes per Conductor					
30	3	3	3	4	4
28	4	4	5	6	6
26	5	5	6	7	8
24	7	7	8	10	11
22	9	10	11	13	14
20	12	13	14	17	19
18	25	20	22	26	29
16	27	28	30	36	38
Correction Factors For Various Air Temperatures					
30C	1.00	1.00	1.00	1.00	1.00
40	0.91	0.93	0.95	0.97	0.98
50	0.82	0.85	0.89	0.94	0.95
60	0.71	0.77	0.83	0.91	0.93
70	0.58	0.68	0.76	0.87	0.91
80	0.41	0.57	0.69	0.84	0.87
90	...	0.44	0.61	0.80	0.83
100	...	0.25	0.51	0.77	0.80
125	...	...	...	0.66	0.69
150	...	...	...	0.54	0.56
200	...	...	...	...	0.43

CURRENT RATING FOR DIFFERENT CONDUCTOR MATERIALS MAY BE CALCULATED BY MULTIPLYING THE APPROPRIATE COPPER CONDUCTOR RATING BY THE FOLLOWING FACTORS:

Nickel - clad copper 0.87
Nickel 0.43

Note: The ultimate temperature an appliance wire reaches is influenced more by its proximity to heat sources (resistors, motors, etc.), within the appliance than by the current flowing in the wire itself. The ratings, therefore, should only be used as a guide. In no case should the wire be used in a manner that will cause it to exceed its maximum temperature rating.

AUDIO LINE TABLE

This chart shows the maximum length of line that can be used between an amplifier and speaker(s) that would assure that the power loss does not exceed 15% in low-impedance circuits, and 5% in high-impedance circuits.

When several speaker lines are brought separately to an amplifier, calculations must be made for each line independently.

FOR EXAMPLE: Four 16-ohm speakers are connected in parallel to the 4-ohm tap for perfect impedance match. Line losses are calculated for each line on the basis of the 16-ohm impedance rather than the combined 4-ohm impedance.

Maximum Length of Line for 15% Power Loss—Low Impedance Lines

Wire Size (B and S)	Load Impedance		
	4 ohms	8 ohms	16 ohms
14	125 ft	250 ft	450 ft
16	75 ft	150 ft	300 ft
18	50 ft	100 ft	200 ft
20	25 ft	50 ft	100 ft

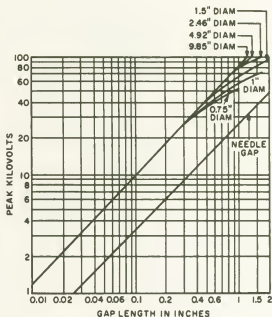
Maximum Length of Line for 5% Power Loss—High Impedance Lines

Wire Size (B and S)	Load Impedance		
	100 ohms	250 ohms	500 ohms
14	1000 ft	2500 ft	5000 ft
16	750 ft	1500 ft	3000 ft
18	400 ft	1000 ft	2000 ft
20	250 ft	750 ft	1500 ft

SPARK-GAP BREAKDOWN VOLTAGES

The curves are for a voltage that is continuous or at a frequency low enough to permit complete deionization between cycles, between needle points, or clean, smooth, spherical surfaces (electrodes ungrounded) in dust-free clean air. Temperature is 25°C and pressure is 760 mm (29.9 in.) of mercury. Peak kilovolts shown in the graph should be multiplied by the factors given in the table for other atmospheric conditions.

An approximate rule for uniform fields at all frequencies up to at least 300 MHz is that the voltage breakdown gradient of air is 30 peak kV/cm or 75 peak kV/in. at sea level (760 mm of mercury) and normal temperature (25°C). The breakdown voltage is approximately equal to pressure and inversely proportional to absolute (° Kelvin) temperature.



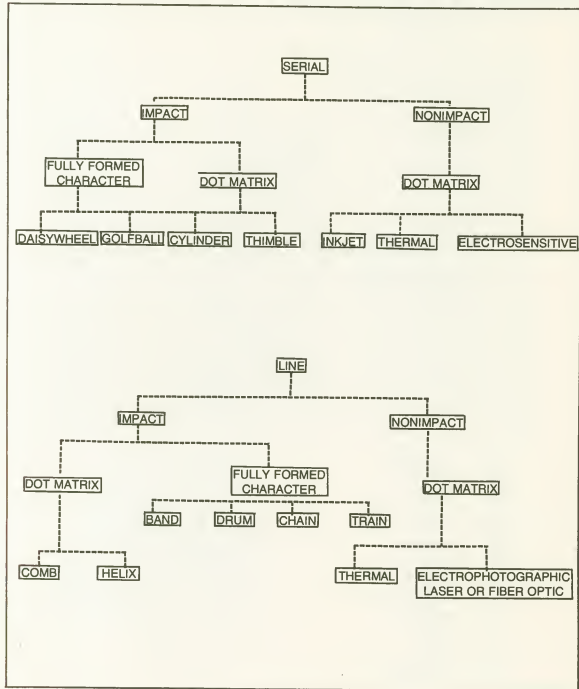
Spark-gap breakdown voltages.

Table of Multiplying Factors

Pressure		Temperature (°C)					
(in. Hg)	(mm Hg)	-40	-20	0	20	40	60
5	127	0.26	0.24	0.23	0.21	0.20	0.19
10	254	0.47	0.44	0.42	0.39	0.37	0.34
15	381	0.68	0.64	0.60	0.56	0.53	0.50
20	508	0.87	0.82	0.77	0.72	0.68	0.64
25	635	1.07	0.99	0.93	0.87	0.82	0.77
30	762	1.25	1.17	1.10	1.03	0.97	0.91
35	889	1.43	1.34	1.26	1.19	1.12	1.05
40	1016	1.61	1.51	1.42	1.33	1.25	1.17
45	1143	1.79	1.68	1.58	1.49	1.40	1.31
50	1270	1.96	1.84	1.73	1.63	1.53	1.44
55	1397	2.13	2.01	1.89	1.78	1.67	1.57
60	1524	2.30	2.17	2.04	1.92	1.80	1.69

PRINTERS

The family trees show the various types of serial and parallel printers and how they relate.



ASCII CODE

The American Standard Code for Information Interchange (ASCII code) is used extensively in computer data transmission. The ASCII Code produced by most computer keyboards is shown here.

BIT NUMBERS								0 ₀ 0	0 ₀ 1	0 ₁ 0	0 ₁ 1	1 ₀ 0	1 ₀ 1	1 ₁ 0	1 ₁ 1
b ₇	b ₆	b ₅	b ₄	b ₃	b ₂	b ₁	COLUMN ROW	0	1	2	3	4	5	6	7
			0	0	0	0	0	NUL	DLE	SP	0	@	P	\	p
			0	0	0	1	1	SOH	DC1	!	1	A	Q	o	q
			0	0	1	0	2	STX	DC2	"	2	B	R	b	r
			0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
			0	1	0	0	4	EOT	DC4	\$	4	D	T	d	t
			0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
			0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
			0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
			1	0	0	0	8	BS	CAN	(	8	H	X	h	x
			1	0	0	1	9	HT	EM	)	9	I	Y	i	y
			1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
			1	0	1	1	11	VT	ESC	+	;	K	[	k	{
			1	1	0	0	12	FF	FS	,	<	L	\	l	l
			1	1	0	1	13	CR	GS	-	=	M	]	m	}
			1	1	1	0	14	SO	RS	.	>	N	^	n	~
			1	1	1	1	15	SI	US	/	?	O	_	o	DEL

NUL Null, or all zeros
 SOH Start of heading
 STX Start of text
 ETX End of text
 EOT End of transmission
 ENQ Enquiry
 ACK Acknowledge
 BEL Bell, or alarm
 BS Backspace
 HT Horizontal tabulation
 LF Line feed
 VT Vertical tabulation
 FF Form feed
 CR Carriage return
 SO Shift out
 SI Shift in
 DLE Data link escape

DC1 Device control 1
 DC2 Device control 2
 DC3 Device control 3
 DC4 Device control 4
 NAK Negative acknowledge
 SYN Synchronous idle
 ETB End of transmission block
 CAN Cancel
 EM End of medium
 SUB Substitute
 ESC Escape
 FS File separator
 GS Group separator
 RS Record separator
 US Unit separator
 SP Space
 DEL Delete

BAUDOT CODE

The Baudot Code is a 5-bit code suitable for punched paper tape and standard teletypewriter operation. In addition to the five bits per character, each character is preceded by a start bit, which is a space, followed by a stop bit, which is a mark, approximately 1½ times longer than the regular data mark.

CHARACTER		IMPULSE POSITION				
LOWER CASE	UPPER CASE	1	2	3	4	5
A	-	●	●			
B	?	●			●	●
C	:		●	●	●	●
D	\$	●			●	
E	3	●				
F	!	●			●	●
G	@		●		●	●
H	#			●	●	●
I	8		●	●	●	
J	,	●	●		●	
K	(●	●	●	●	
L)		●		●	●
M	.			●	●	●
N	,			●	●	
O	9				●	●
P	0		●	●	●	●
Q	1	●	●	●	●	●
R	4		●		●	
S	Bell	●		●		
T	5					●
U	7	●	●	●		
V	;		●	●	●	●
W	2	●	●			●
X	/	●		●	●	●
Y	6	●		●	●	●
Z	"	●				●
LETTERS Lower Case		●	●	●	●	●
FIGURES Upper Case		●	●		●	●
SPACE				●		
CARRIAGE RETURN					●	
LINE FEED			●			
BLANK						

NOTE: PRESENCE OF ● INDICATES MARKING IMPULSE

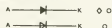
ABSENCE OF ● INDICATES SPACING IMPULSE

GRAPHIC SYMBOLS FOR ELECTRONIC DIAGRAMS

Semiconductors

DIODES

rectifier (junction) diode



zener (unidirectional breakdown) diode



bidirectional breakdown diode



constant current (field effect) diode



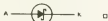
tunnel diode



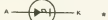
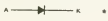
tunnel rectifier (backward diode)



Schottky (hot carrier) diode



p-n diode



Gunn diode, also Impatt diode



step-recovery (snap, charge storage) diode

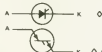


varactor (variable-capacitance) diode



THYRISTORS

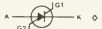
four-layer (pnpn, Shockley) diode



silicon controlled rectifier (SCR)



silicon controlled switch (SCS)



diac (bidirectional switch)



triac (gated bidirectional switch)

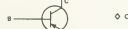


TRANSISTORS

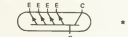
npn transistor



pnp transistor



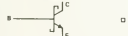
multiple emitter npn transistor



nnp Darlington transistor



nnp Schottky transistor



unijunction transistor (UJT) with n-type base



unijunction transistor (UJT) with p-type base



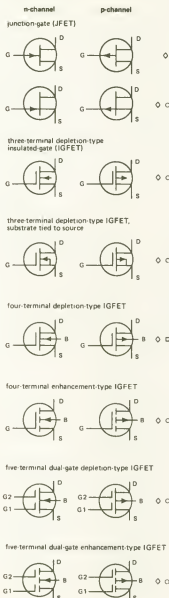
programmable unijunction transistor (PUT), also SCR with n-type gate



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Optoelectronic Devices

FIELD-EFFECT TRANSISTORS (FETs)

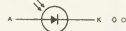


DIODES

light-emitting diode (LED)



photodiode



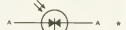
npn bidirectional photodiode (photo-duo-diode)



pnip bidirectional photodiode (photo-duo-diode)



pnip two-segment photodiode, with common cathode

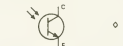


pnip four-quadrant photodiode, with common cathode

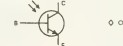


TRANSISTORS

npn phototransistor, no base connection

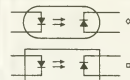


npn phototransistor, with base connection

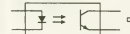


OPTICALLY COUPLED ISOLATORS

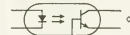
with photodiode output



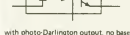
with phototransistor output, no base connection



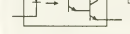
with phototransistor output, and base connection



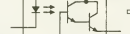
with photo-Darlington output, no base



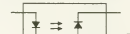
with photo-Darlington output, and base



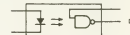
with photodiode and amplifier-transistor output



with photodiode and amplifier-transistor output



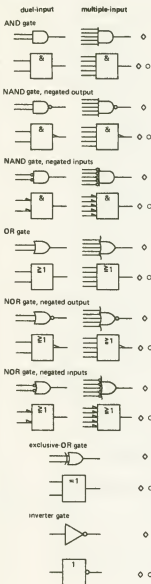
with NAND-gate-photodetector output



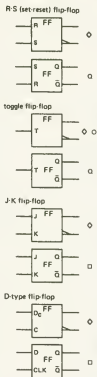
◇ = IEEE/ANSI approval ○ = IEC approval * = Proposed IEEE revision □ = Popular industry usage √ = NARM approval

Two-State Logic Devices

GATES



FLIP-FLOPS



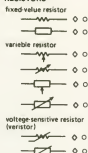
MONOSTABLE MULTIVIBRATOR



SCHMITT TRIGGER



RESISTORS



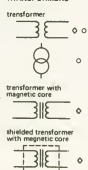
CAPACITORS



INDUCTORS



TRANSFORMERS



Fundamental Circuit Components

CRYSTALS



BATTERIES



SOURCES



LAMPS



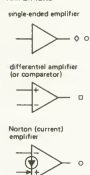
CIRCUIT PROTECTORS



AUDIO DEVICES



AMPLIFIERS



Contacts, Switches, and Relays

CONTACTS

fixed relay contact



fixed switch contact



moving contact, locking



moving contact, nonlocking



closed contact



open contact



make before-break contact assembly



break before-make contact assembly



SWITCHES

single pole single throw (spst)



single pole double-throw (spdt)



double pole double-throw (dpdt)



push button switch, normally open



push button switch, normally closed



multiposition switch



RELAY CONTACT ARRANGEMENTS

three arm indicators, direction of operation



Form A, spst, normally open (make)



Form B, spst, normally closed (break)



Form C, spdt (break, make)



Form D, spdt (make, break)



Transmission Path

CABLE

two conductor cable with grounded shield



coaxial cable with grounded shield



twisted pair



WAVEGUIDE

circular waveguide



rectangular waveguide



flexible waveguide



twisted waveguide



STRIPLINE

unbalanced stripline



balanced stripline



GROUND

earth ground



chassis in frame connection



Microwave Circuits

COUPLING

coupling by loop to space



coupling by loop to guided transmission path



coupling by loop from coaxial to circular waveguide, with dc grounds connected



DIRECTIONAL COUPLERS

dual directional coupler



HYBRID JUNCTIONS

waveguide hybrid junction



stripline hybrid junction



CIRCULATORS

fixed-direction circulator



reversible-direction circulator



MODE SUPPRESSORS

for both coaxial and waveguide transmission



FILTERS

mode filter



bandpass filter



low pass filter



high-pass filter



band-reject filter



PHASE SHIFTERS

matched phase shifter



CONVERSION TABLE FOR BASIC PHYSICAL UNITS

	CGS-ESU	Multiply by to get CGS-EMU		Multiply by to get Rationalized MKS	
1. Length	Centimeter	1	Centimeter	10 ⁻²	Meter
2. Mass	Gram	1	Gram	10 ⁻³	Kilogram
3. Force	Dyne	1	Dyne	10 ⁻⁵	Newton, Dyne-five
4. Energy, Work	Erg	1	Erg	10 ⁻⁷	Joule
5. Power	Erg/second	1	Erg/second	10 ⁻⁷	Watt
6. Electric Charge	Statcoulomb	3.335 x 10 ⁻¹¹	Abcoulomb	10	Coulomb
7. Linear Charge Density	Statcoulomb/cm.	3.335 x 10 ⁻¹¹	Abcoulomb/cm.	10 ³	Coulomb/m.
8. Surface Charge Density	Statcoulomb/cm. ²	3.335 x 10 ⁻¹¹	Abcoulomb/cm. ²	10 ⁵	Coulomb/m. ²
9. Volume Charge Density	Statcoulomb/cm. ³	3.335 x 10 ⁻¹¹	Abcoulomb/cm. ³	10 ⁷	Coulomb/m. ³
10. Electric Flux	Statcoulomb	3.335 x 10 ⁻¹¹	Abcoulomb	10	Coulomb
11. Displacement, Electric Flux Density	Statcoulomb/cm. ²	3.335 x 10 ⁻¹¹	Abcoulomb/cm. ²	10 ³	Coulomb/m. ²
12. Polarization	Statcoulomb/cm. ²	3.335 x 10 ⁻¹¹	Abcoulomb/cm. ²	10 ³	Coulomb/m. ²
13. Electric Dipole Moment	Statcoulomb-cm.	3.335 x 10 ⁻¹¹	Abcoulomb-cm.	10 ⁻¹	Coulomb-m.
14. Potential	Statvolt	2.998 x 10 ¹⁰	Abvolt	10 ⁻⁸	Volt
15. Electric Field Intensity	Statvolt/cm.	2.998 x 10 ¹⁰	Abvolt/cm.	10 ⁻⁶	Volt/m.
16. Current	Statampere	3.335 x 10 ⁻¹¹	Abampere	10	Ampere
17. Surface Current Density	Statampere/cm.	3.335 x 10 ⁻¹¹	Abampere/cm.	10 ³	Ampere/m.
18. Volume Current Density	Statampere/cm. ²	3.335 x 10 ⁻¹¹	Abampere/cm. ²	10 ⁵	Ampere/m. ²
19. Resistance	Statohm	8.988 x 10 ¹⁰	Abohm	10 ⁻⁹	Ohm
20. Resistivity	Statohm-cm.	8.988 x 10 ¹⁰	Abohm-cm.	10 ⁻¹¹	Ohm-m.
21. Conductance	Statmho	1.113 x 10 ⁻²¹	Abmho	10 ⁹	Mho
22. Conductivity	Statmho/cm.	1.113 x 10 ⁻²¹	Abmho/cm.	10 ¹¹	Mho/m.
23. Capacity	Statfarad, Cm.	1.113 x 10 ⁻²¹	Abfarad	10 ⁹	Farad
24. Elastance	Statdaraf	8.988 x 10 ²⁰	Abdaraf	10 ⁻⁹	Daraf
25. Dielectric Constant, Permittivity	—	1.113 x 10 ⁻²¹	—	.7958 x 10 ¹⁰	Farad/m.
26. Inductance	Stathenry	8.988 x 10 ²⁰	Abhenry (Centimeter)	10 ⁻⁹	Henry
27. Permeability	—	8.988 x 10 ²⁰	Gauss/Oersted	1.257 x 10 ⁻⁶	Henry/m.
28. Reluctivity	—	1.113 x 10 ⁻²¹	Oersted/Gauss	10 ⁷	—
29. Magnetic Charge	—	2.998 x 10 ¹⁰	Unit Pole	1.257 x 10 ⁻⁷	Weber
30. Magnetic Flux	—	2.998 x 10 ¹⁰	Maxwell (Line)	10 ⁻⁸	Weber
31. Magnetic Flux Density, Magnetic Induction	—	2.998 x 10 ¹⁰	Gauss, Lines/cm. ²	10 ⁻⁴	Weber/m. ²
32. Magnetization	—	2.998 x 10 ¹⁰	Pole/cm. ²	1.257 x 10 ⁻²	Weber/m. ²
33. Magnetic Dipole Moment	—	2.998 x 10 ¹⁰	Pole-cm.	1.257 x 10 ⁻⁹	Weber-m.
34. Magnetic Field Intensity, Magnetizing Force	—	3.335 x 10 ⁻¹¹	Oersted (Gilbert/cm.) (Gauss)	10 ² .7958 x 10 ²	Praoersted Ampere-turn/m.
35. Magnetomotive Force	—	3.335 x 10 ⁻¹¹	Gilbert	10 .7958	Pragilbert Ampere-turn
36. Reluctance	—	1.113 x 10 ⁻²¹	Gilbert/Maxwell (Oersted)	10 ⁹ .7958 x 10 ⁹	Pragilbert/Weber Ampere-turn/Weber
37. Permeance	—	8.988 x 10 ²⁰	Maxwell/Gilbert	10 ⁻⁹ 1.257 x 10 ⁻⁸	— Weber/Ampere-turn

Practical System: Incomplete system similar to MKS, but using centimeters and grams.

For all Systems: Temperature is in °C. Time is in seconds.

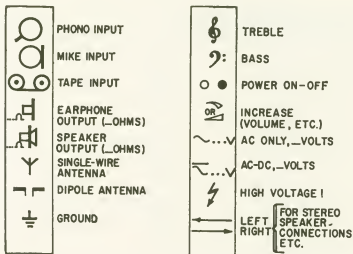
For MKS System: Space Permittivity 8.854×10^{-12} F/m. Space permeability 1.257×10^{-6} H/m.

Older or obsolete names are shown in parentheses.

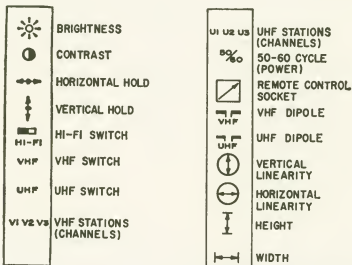
To convert CGS-ESU to Rationalized MKS, multiply by both factors.

TERMINAL AND CONTROL MARKINGS ON FOREIGN EQUIPMENT

Radio-Phono



Television



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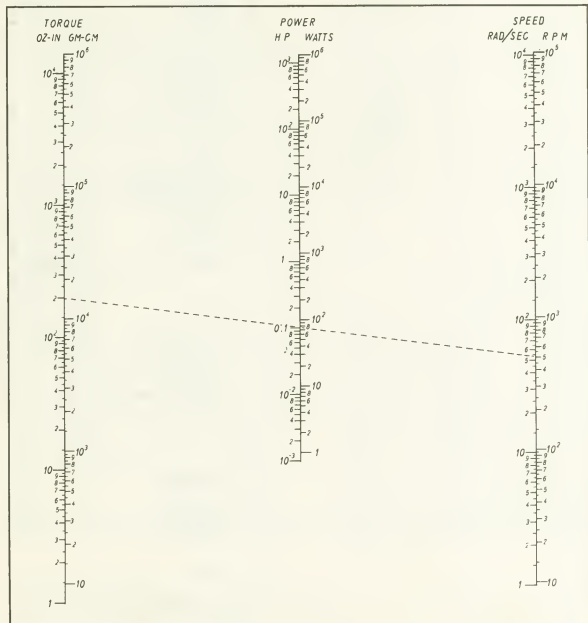
TORQUE-POWER-SPEED NOMOGRAM

This nomogram relates power, torque, and speed.

FOR EXAMPLE: 200 oz-in. at 500 rpm is 0.1 hp, which equals approximately 75 W. The nomogram is based on the formula:

$$\text{Horsepower} = 9.92 \times \text{torque} \times \text{speed} \times 10^{-7}$$

where torque is in ounce-inches and speed in revolutions per minute.



APPROXIMATE FULL-LOAD CURRENT FOR CONTINUOUS-DUTY MOTORS

Direct-Current Motors^a
(Amperes at Full Load)

HP	115 V	230 V	550 V
1/2	4.6	2.3	
3/4	6.6	3.3	1.4
1	8.6	4.3	1.8
1 1/2	12.6	6.3	2.6
2	16.4	8.2	3.4
3	24	12	5.0
5	40	20	8.3
7 1/2	58	29	12.0
10	76	38	16.0
15	112	56	23.0
20	148	74	31
25	184	92	38
30	220	110	46
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	184
150		534	220
200		712	295

Single-Phase, Alternating-Current Motors^b
(Amperes at Full Load)

HP	115 V	230 V	440 V
1/6	3.2	1.6	
1/4	4.6	2.3	
1/2	7.4	3.7	
3/4	10.2	5.1	
1	13	6.5	
1 1/2	18.4	9.2	
2	24	12	
3	34	17	
5	56	28	
7 1/2	80	40	21
10	100	50	26

For full-load currents of 208- and 200-V motors, increase corresponding 230-V motor full-load current by 10% and 15%, respectively.

^aThese values for full-load current are average for all speeds.

^bThese values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the name plate current rating should be used.

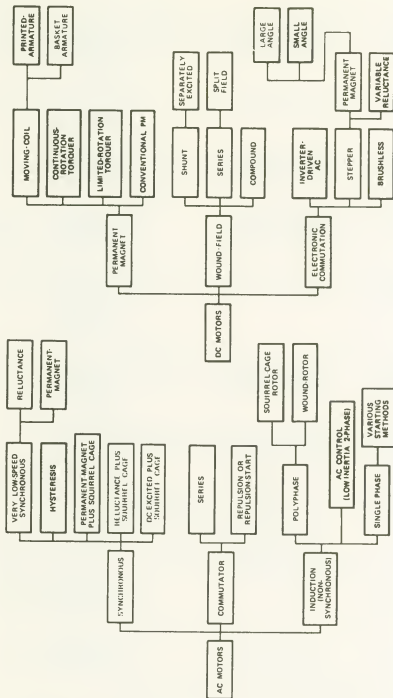
CHARACTERISTICS OF SELECTED MOTOR TYPES

Motor Type	Basic Characteristics	Performance Ranges	Application Areas
CONVENTIONAL PERMANENT-MAGNET	A simple alternative to wound-field shunt. PM field plus wound armature. Linear torque-speed relationships in small units. Life limited by brushes in high-speed or severe applications. Readily controlled by transistors or SCR's.	Output from 1W to a fraction of a horsepower. Time constants 0.625% of no-load speed to <10 msec. Efficiencies from 60 to 70% in 10W sizes. With new magnet materials, can deliver high peak powers (horsepower range).	For full range of responsive, good-performance drive and control applications. With appropriate environmental precautions, suitable for military/severe use. Preferred as a high performance, general-purpose servo motor.
LIMITED-ROTATION DC TORQUE	No commutator wear or friction. Unlimited life. Infinite resolution. Smooth, cog-free rotation. No EMF generation. Available as motor elements or fully housed.	Travel range typically to 120°. Torque from a low oz-in to >40 lb-ft. Mechanical time constants from 10 to 50 msec.	Very high-accuracy positioning or velocity control over a limited angle.
CONTINUOUS-ROTATION DC TORQUE	Slow speed, high torque. Relatively low power output. Available as pole-pair-shaped components. Wide dynamic range. Large number of coils give smooth operation.	From 10's of oz-in to 100's of ft-lb. Moderate mechanical time constants. Control to seconds of sec. Relatively expensive.	For direct coupling to load. For very precise control. Alternative to geared types.
MOVING-COIL/PRINTED-ARMATURE (IRONLESS MOTOR)	Similar to permanent-magnet dc axils. Linear torque-speed characteristics. Smooth, noncogging rotation. Handles very high, short-duration peak loads. Fast response (<10 msec).	Outputs from <1W to fractional horsepower. High efficiencies. Very low mechanical and electrical time constants.	Computer peripherals where smooth control and fast response are needed. Control applications needing high response bandwidth, fast starting and stopping.
VARIABLE-RELUCTANCE STEPPER	Roughness and rugged. High stepping rate dependent on driver circuitry. No locking torque at zero energization. Poor inherent dynamic. Low power efficiency. Can exhibit resonance. Operates open loop. Wide dynamic range. Easily controlled. Very reliable and low in cost in popular frame sizes.	Several hundred to thousands of gps. Power output up to a few hundred watts.	Alternative to synchronous motor. Used in control applications where fast response rather than high power is the principal requirement. Interface well to digital computers.
SMALL SHAFT PERMANENT-MAGNET STEPPER	Uses variable principle to give very small stepping angles. High stepping rates. High cogging torques with zero input power. Efficiency usually very low.	Stepping rate from <100 pps to many 1000's. Dependent on driver electronics. Power up to a few hundred watts. Single step takes a few milliseconds.	Useful in numerical control and actuator application where control is digital. Provides fast slowing and high-resolution tracking.
INVERTER-DRIVEN AC	Operates from dc line using a switching inverter. Somewhat less efficient than ac induction motors, otherwise similar in performance. Single-phase (capacitor) or 2-phase versions most common.	Outputs from <1W to fractional horsepower. Efficiencies from 70 to 80% in larger models. Speeds up to 30,000 RPM and higher.	Use where dc is only power available. For general applications where ac supplies vary widely, as in furnace applications. Use where brushes might not be sufficiently reliable, as in very high speeds or in severe environments. Variable-frequency versions used in accelerating high inertial loads.
BRUSHLESS DC	PM units using electronic commutation of stator "armature". Exhibits conventional dc motor characteristics, but torque modulation with rotation is higher. Lack of brushes gives reliability in difficult applications.	From <1W to 1-2 hp. Relatively high time constants. Speeds to 30,000 RPM. Efficiency to 80%. Voltages to 100's of Vdc.	For brushless, long-life applications requiring superior efficiency and control. May be operated at very high altitudes or totally submerged.
AC CONTROL	Brushless. 2-phase. Low inertia. Scalable cage. Linear torque-speed curves in small units. Increasing cavitation for units >20W. Damping falls off at low control voltages. Efficiency very low (10-30%). Poor overload capability.	Primarily used in low-power-output applications (<1W to 50W). Available in 60 and 400 Hz versions. Time constants in the 10's of milliseconds.	Recommended for ac carrier systems requiring very low output power. Very small sizes (0.5 in. dia) available. Used in many military systems because of high motor reliability.
HYSTERESIS	Synchronous. Low-to-moderate efficiency. Moderate starting torque. Synchronization independent of load inertia. Smooth, cog-free torque. Low heating.	Power output up to about 150W. Speeds up to 30,000 RPM. Efficiencies can exceed 50%.	Use where synchronous operation required. Suited to constant speed computer peripheral applications.
NOTES	*Variants of these motors using newly developed, very high energy rare-earth magnets can now be made in compact integral horsepower sizes with very high peak overload capability.		

Specific Applications	Comparisons with Other Motors	Selection and Application Factors
Preferred for actuators where high peak and steady power (100's of watts) and fast response (10 to 20 msec) required Basic drive in aircraft control systems	Higher efficiency, damping, lower electrical time constants than comparable ac control motors, except in very low-power applications Far more efficient than stepper drives More easily controlled than other motor types	Select for safe operation with acceptable temperature rises Check operating conditions for abrupt starts or reversals which can demagnetize PM fields Check for altitude or environmental effects on brushes, especially over 10,000 RPM High stall currents are drawn in efficient or high-power motors Low-output-impedance electronic control required to utilize inherent motor damping
Frequently used in equipment incorporating gyros Pawable shape a significant asset in gyro gimbal Gives smooth, frictionless control	Much simpler than continuous rotation linkages with or without commutators	Suitable for direct-drive, unbalanced, high-accuracy mechanical control Similar wide-angle brushless tachometers available Requires high-power driving amps
Highest precision military and aerospace applications Autonomous positioning and tracking to within seconds of arc Used in super accurate multichannel resolvers Wide response band useful in high-accuracy stable platforms Used with grey scale tables	Supplies most precise control, smooth, and accurate tracking for continuous-rotation applications Requires higher powered amps compared with geared units	Shift direct coupling to load preferred PWM amps preferred for high control power
Small, inexpensive units find use in computer peripherals like tape drives and card readers Ideal for control and automatic applications.	Faster response than iron-rotor motors Excellent brush life Lower starting voltages, limited only by brush friction Much more efficient than stepper motors	Recommended for low cogging, low starting voltage, fast response applications Rotor heats up quickly Thermal transients and heat removal can be important factors Larger, high-performance units can be expensive Low armature inductance permits commutation at very high current surges
Used as computer-peripheral drivers (floppy discs, card readers) where motor determinates response limits Gearing provided by driving electronics Simple, low-cost alternative to laser positioners in positioning floppy disc heads Can be used in closed-loop applications	Power output and efficiency generally very low compared with dc control motors	Care required in application Performance dependent on electronic driver circuitry Heat dissipation a possible problem At certain pulse rates resonance can occur which reduce load-handling capability Load inertia reduces performance Friction can improve damping Damping, gearing and mechanical couplings require special attention.
Provides very low cost open-loop control in actuator arrays Cogging torque reflected through gear train might obviate brake requirements Where feedback is required, can be used with optical incremental encoder discs	Efficiency of shaft power generation is low More flexible than comparable means Simple and inexpensive alternative to synchronous or wide-speed-range drives Handles higher load inertia than variable-reluctance stepper and has better damping	Choose where special control characteristics are preferred over efficiency Check for resonances at all pulse rates Gearing can require extra safety margins because of impacts inherent in stepper operation. Coupling compliances can help in accelerating load inertia, but additional resonances can be introduced. Driver-circuit design is critical Standard drivers available.
Useful in ten applications for high-reliability computer equipment For high altitude, severe environment applications where brushes fail	Less efficient than true brushless motors using electronic commutation More complex, expensive and noisier than brush-type dc motors Less suitable for control than other dc types Very long life with properly designed inverter	Inverter can be separate or packaged with motor High-line-critical supply EMI generation, with bulky filter capacitors required for suppression SCR inverters preferred in higher power uses, but transistor inverters are easier to switch and more reliable Power-supply capacitors can be required and must withstand supply transients
Ideal for high-altitude fans Suitable for pumps where fluid in the airgap does not significantly degrade operation Used in very high-speed machine tools	More efficient, easier to control, generate less EMI than inverter type motors Commutating transistors can be used for speed control, reversing current and torque limiting without a separate controller, unlike other types Delivers highest sustained output in a given package size	Electronics can be packaged externally or within motor housing High mesh line currents Bulky line filter required if EMI is a problem Power-supply capacitors could be required With properly designed electronics, life is limited only by bearings. Temperatures can set limits to some commutation sensors
Instrument serves for military applications 400 Hz carrier leads to higher shaft power, motor efficiency and smaller size Direct drive, feedback transducers and mechanical devices Frequently simpler than all-electronic systems in applications requiring only output displays	Efficiency, power output and overload capability are poor compared with dc devices Suitable for very low-power applications because there is no brush friction and less cogging	Other design, good proven units generally available For critical applications, use tachometer damping because inherent damping is unelectable and network damping difficult to apply Required 90° phase shift is best supplied by the control amp Main field-capacitor phase shift only convenient in very small motors Main field power keeps units hot even while idling
Useful in driving memory discs, which require uniform, cog-free torque over short distances, freedom from bearing play and maximum speed modulation Used in precision gyro drives	Somewhat less efficient than salient-pole synchronous machines of either wound-field or PM construction Less hunting than other types of synchronous motors Simpler than phase-locked drives	High efficiencies important for computer applications Low power factors lead to high input currents Higher power factors available in single-phase capacitor versions Sensitive to input harmonics Can accelerate high-inertia loads Does not have a preferred synchronization angle

*These types have low rotor thermal capacities to gauge the heat rise it takes about 200W to raise the temperature of a 1-lb armature by 1°C in 1 sec. Other values can be suitably proportioned

(Reprinted from "Motor Comparison Chart," EDN, August 5, 1978, pages 97-99, courtesy EDN.)



(Reprinted from "Motor Comparison Chart," EDW, August 5, 1978, pages 97-99, courtesy EDN.)

POWER CONSUMPTION OF ELECTRICAL EQUIPMENT

Device	Average Rating (Watts)
Air Cleaner	50
Air Conditioner (room)	1,500
Blender	390
Broiler	1,450
Carving Knife	100
Clock	2
Clothes Dryer	4,850
Coffee Maker	900
Deep Fryer	1,450
Dehumidifier	250
Dishwasher	1,200
Electric Blanket	175
Fan:	
attic	370
furnace	290
window	200
Floor Polisher	300
Freezer:	
(14 cu. ft.)	340
(frostless - 15 cu. ft.)	440
Frying Pan	1,200
Heater (portable)	1,320
Heating Pad	65
Hot Plate	1,250
Humidifier	175
Iron (Hand)	1,000
Microwave Oven	1,450
Mixer	125
Oil Burner (stoker)	265
Radio	70
Radio /Record Player	100
Range with oven	12,200
Refrigerator:	
(12 cu. ft.)	300
(frostless, 12 cu. ft.)	390
Refrigerator /Freezer:	
(14 cu. ft.)	352
(frostless, 14 cu. ft.)	600
Roaster	1,300
Sandwich Grill	1,150
Sewing Machine	75
Television:	
black and white:	
tube type	160
solid state	55
color TV:	
tube type	300
solid state	200
Toaster	1,150
Trash Compactor	400
Vacuum Cleaner	630
Waffle Iron	1,100
Washing Machine:	
automatic	500
nonautomatic	280
Waste Disposer	440
Water Heater:	
standard	2,475
quick recovery	4,475
Water Pump	460

NOMOGRAM RELATING AMPLITUDE, FREQUENCY, AND ACCELERATION OF A BODY WITH SIMPLE HARMONIC MOTION

This nomogram is based on the formula

$$g = 0.10225 (d) (f)^2$$

where

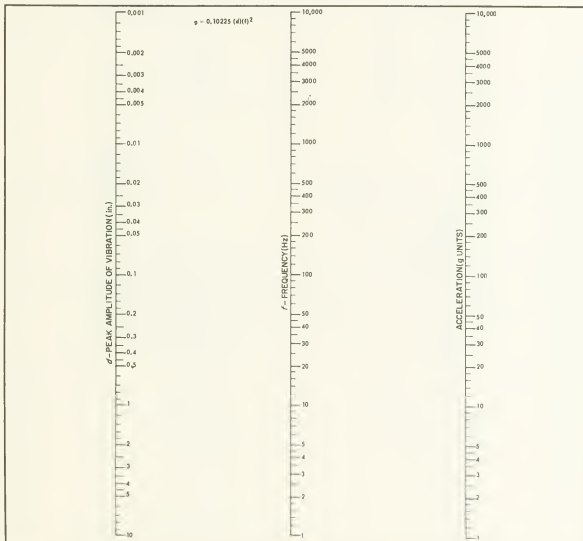
g = acceleration in g-units

f = frequency of vibration in cps

d = amplitude of vibration (peak displacement each side of resting point) in inches

FOR EXAMPLE: A vibrating body with a displacement of 0.01 in. each side of center at 200 Hz, has an acceleration of 40 g's.

NOTE: To find the acceleration in a rotating body resulting from centrifugal force, substitute radius of rotation for amplitude (d), and revolutions per second for vibrations per second (f). $g = 32 \text{ ft/sec/sec}$ in the MKS system of units.



SHOCK DECELERATION NOMOGRAM

This nomogram relates deceleration (G load), stopping distance, and drop height as an aid to designers and engineers who must deal with problems of shock caused by violent or sudden deceleration.

The equation used to plot the nomograph is $\log G = \log g + \log H - \log D$. Relating deceleration (G load), stopping distance, and drop height, it is based on the following relationships:

$$\begin{aligned}H &= gt^2 / 2 \\D &= Gt'^2 / 2 \\V &= gt \\V_i &= Gt'\end{aligned}$$

where:

$$\begin{aligned}H &= \text{free-fall distance} \\g &= \text{acceleration due to free fall} \\t &= \text{free-fall time} \\D &= \text{stopping or deflection distance} \\G &= G \text{ load due to impact shock} \\t' &= \text{deceleration time} \\V &= \text{terminal velocity due to free fall at instant of impact} \\V_i &= \text{initial deceleration velocity at instant of impact}\end{aligned}$$

Since at the moment of impact the terminal velocity (V_i) caused by acceleration is equal to the initial velocity (V), it follows that:

$$gt = Gt'$$

Combining the equations:

$$H/D = \frac{gt^2 / 2}{Gt'^2 / 2} = gt / Gt' (t')$$

Since $gt = Gt' H / D = t / t'$. Also, since $G/g = t/t'$, $H/D = G/g$. Transposing, $G = g(H/D)$ or $\log G = \log g + \log H - \log D$. This equation is based on a constant or uniformly decelerating force. For linear deceleration the equation for load distance relationship is: $G = 2gH/D$.

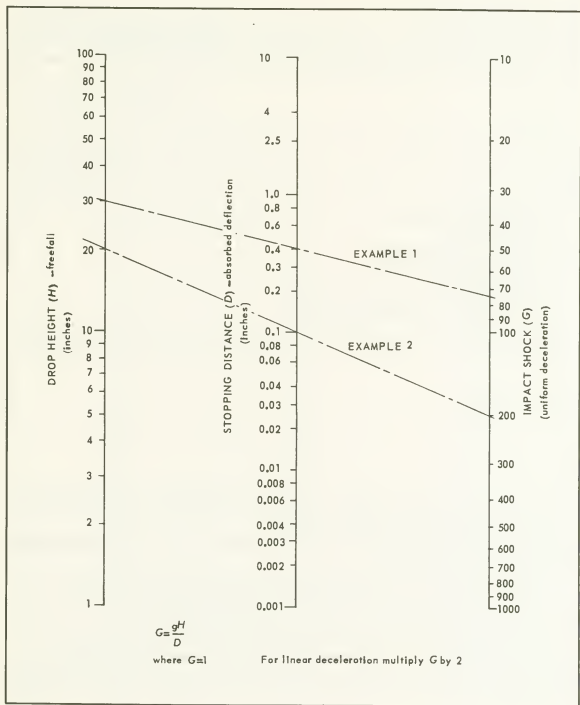
Neither formula includes the stopping distance as part of the distance traveled because its effect is negligible for small values of stopping distance (D).

FOR EXAMPLE: 1. Find the G load on a shock-mounted case that endures a 30-in. drop height with a maximum mount deflection of 0.4 in. Assume a rigid case and uniform deceleration in the mount.

ANSWER: Intersect impact shock (G) scale with a line connecting the 30-in. drop height with 0.4 in. on the absorber deflection scale. Read answer off impact shock scale. In this example, it is 73G.

2. Find the impact shock on a piece of equipment that is dropped 20 in. on expanded rubber foam gasket. The foam is compressed a total of 0.1 in. and is assumed to have a linear deceleration characteristic.

ANSWER: Intersect the impact shock (G) scale with a line connecting the 20-in. drop height with 0.1 in. on the absorber deflection scale. Since peak impact shock (G) load due to linear deceleration is approximately twice as severe as that due to uniform deceleration, the value of 200G obtained is multiplied by 2 for linear deflection. Answer is 400G.

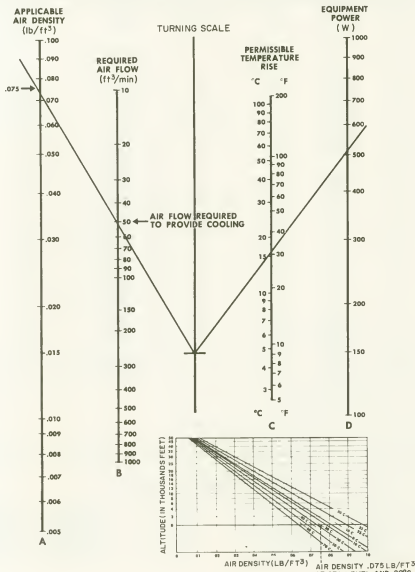


AIR-COOLING NOMOGRAM

For a given power dissipation and air density, this nomogram solves for the air flow (cubic feet per minute) that is required to keep the temperature rise of an equipment at a specified value. At sea level (760 mm Hg), 0°C, and an air density of 0.079 lb/ft³, the temperature rise is approximately equal to 3,000 P/Q, where P is power dissipation in kilowatts and Q is the air flow in cubic feet per minute.

To use the nomogram first determine the ambient temperature and altitude at which the equipment must operate and note from the graph the applicable air density for these conditions. On the nomogram align the permissible temperature rise with the equipment's power dissipation and note the intersect point on the turning scale. Align this point with the applicable air density and read required air flow in cubic feet per minute on scale B.

FOR EXAMPLE: To operate an equipment with a power consumption of 500 W at sea level, an ambient temperature of 20°C, and a permissible heat rise of 15°C, requires an air flow of 50 ft³/min.



METALLIC ELEMENTS

Name and Symbol	Color	Atomic Weight	Specific Gravity or Density	Specific Heat	Melting-point (°Celsius)	Coefficient of Linear Expansion
Aluminum.....Al	Tin-white	27.1	2.67	0.1140	657	0.000231
Antimony.....Sb	Bluish-white	120.2	6.71-6.86	0.0508	630	0.000195
Arsenic.....As	Steel-gray	75.0	5.72	0.081	450	0.000055
Barium.....Ba	Pinkish-gray	137.4	3.8	0.048	850	—
Beryllium.....Be	Silver-white	9.1	1.8	0.5620	—	—
Bismuth.....Bi	Pinkish-white	208.9	9.825	0.0205	268	0.00014
Bromine.....Br	—	79.8	—	—	—	—
Cadmium.....Cd	Tin-white	112.4	8.546-8.667	0.0548	322	0.000267
Cesium.....Cs	Silver-white	132.9	1.9	0.048	27	—
Calcium.....Ca	Yellow	40.1	1.578	0.1700	800	0.000289
Cerium.....Ce	Gray	140.2	7.64	0.0448	825	—
Chromium.....Cr	Gray	52.0	6.91-7.3	0.1200	1,700	—
Coalt.....C	Grayish-white	59.0	8.5-8.7	0.1070	1,400	0.000125
Columbium.....Cb (see Niobium)	—	—	—	—	—	—
Copper.....Cu	Red	63.6	8.92-8.95	0.0952	1,100	0.000187
Erbium.....Er	—	167.0	—	—	—	—
Ercolinium.....Gd	—	156.0	—	—	—	—
Gallium.....Ga	Bluish-white	69.6	5.9	0.079	30	—
Germanium.....Ge	Bluish-white	72.5	5.5	0.074	800	—
Gold.....Au	Yellow	197.2	19.265	0.0324	1,063	0.000187
Indium.....In	White	114.8	7.42	0.0308	176	0.000136
Iridium.....Ir	Steel-white	192.2	22.38	0.0370	2,250	0.000017
Iron.....Fe	Silver-white	55.8	7.84	0.1140	1,550	0.000285
Lanthanum.....La	Gray	138.9	8.183	0.0449	825	0.000116
Lead.....Pb	Bluish-white	207.2	11.254-11.38	0.0314	328	0.00027
Lithium.....Li	Silver-white	7.02	0.569-0.588	0.9410	—	—
Magnesium.....Mg	Silver-white	24.3	1.75	0.2500	632	0.000289
Manganese.....Mn	Reddish-gray	55.0	8.0	0.1220	1,245	—
Mercury.....Hg	Bluish-white	200.6	13.594	0.0319	—40	0.0000610
Molybdenum.....Mo	Silver-white	96.0	10.222	0.0722	2,450	—
Neodymium.....Nd	—	142.8	7.0	0.080	840	—
Niobe.....Nb	—	92.9	8.8	0.1080	1,450	0.000127
Niobium.....Nb	Steel-gray	92.9	12.1	0.071	1,950	—
Osmium.....Os	Bluish-white	190.8	22.5	0.0311	2,500	0.000085
Palladium.....Pd	Tin-white	106.7	11.4	0.0593	1,548	0.000117
Platinum.....Pt	—	195.2	21.5	0.0324	1,760	0.000089
Potassium.....K	Silver-white	39.10	0.875	0.1560	80	0.000841
Praseodymium.....Pr	—	140.5	8.5	—	860	—
Radium.....Ra	—	225.0	—	—	—	—
Rhenium.....Re	Tin-white	105.8	19.1	0.0560	2,200	0.000085
Rubidium.....Rb	Silver-white	85.5	1.52	0.077	38.5	—
Ruthenium.....Ru	—	101.1	12.261	0.0611	2,400	0.000096
Samarium.....Sm	—	150.3	7.7	—	1,350	—
Scandium.....Sc	—	44.1	—	—	—	—
Silver.....Ag	White	107.9	10.410-57	0.0560	962	0.000192
Sodium.....Na	Silver-white	23.0	0.98	0.293	98	0.000271
Strontium.....Sr	Yellow	87.6	2.5	—	800	—
Tantalum.....Ta	Black	181.6	16.8	0.0365	2,910	0.000079
Tellurium.....Te	—	127.5	8.25	0.049	452	0.000187
Terbium.....Tb	—	160	—	—	—	—
Thallium.....Tl	Bluish-white	204.0	11.8	0.0335	303	0.000302
Thorium.....Th	Gray	232.2	11.2	0.0278	1,690	—
Thulium.....Tm	—	171	—	—	—	—
Tin.....Sn	White	118.0	7.280	0.0558	232	0.000203
Titanium.....Ti	Dark gray	48.1	4.5	0.13	1,800	—
Tungsten.....W	Light gray	184.0	18.29	0.0260	3,300	—
Uranium.....U	Grayish-white	238.0	18.33	0.0277	1,500	—
Vanadium.....V	Whitish-gray	51.1	5.8	0.125	1,880	—
Xenon.....Xe	—	131.3	—	—	—	—
Yttrium.....Y	Gray	88.0	3.80	—	—	—
Zinc.....Zn	Bluish-white	65.4	7.1	0.0955	418	0.000274
Zirconium.....Zr	Gray	90.8	4.15	0.0662	1,300	—

(Reprinted from *Master Handbook of Electronic Tables & Formulas* by Martin Clifford, courtesy TAB BOOKS, Inc.)

DENSITIES OF SOLIDS AND LIQUIDS IN CUBIC CENTIMETERS AND CUBIC FEET

Aluminum.....	2.56 g. per cub. cm.	1.611 lb. per cub. ft.	Platinum.....	21.50 g. per cub. cm.	1,342.2 lb. per cub. ft.
Copper.....	8.9 g. per cub. cm.	555.4 lb. per cub. ft.	Sea Water.....	1.025 g. per cub. cm.	64.0 lb. per cub. ft.
Gold.....	19.3 g. per cub. cm.	1,205.0 lb. per cub. ft.	Silver.....	10.5 g. per cub. cm.	655.5 lb. per cub. ft.
Ice.....	0.9187 g. per cub. cm.	57.2 lb. per cub. ft.	Tin.....	7.28 g. per cub. cm.	448. lb. per cub. ft.
Iron.....	7.87 g. per cub. cm.	491.3 lb. per cub. ft.	Tungsten.....	18.8 g. per cub. cm.	1,181.2 lb. per cub. ft.
Lead.....	11.0 g. per cub. cm.	688.7 lb. per cub. ft.	Uranium.....	18.7 g. per cub. cm.	1,167.4 lb. per cub. ft.
Mercury.....	13.596 g. per cub. cm.	848.7 lb. per cub. ft.	Water.....	1.000 g. per cub. cm.	62.4 lb. per cub. ft.
Nickel.....	8.80 g. per cub. cm.	549.4 lb. per cub. ft.	Zinc.....	7.19 g. per cub. cm.	448.8 lb. per cub. ft.

SOLDER ALLOYS

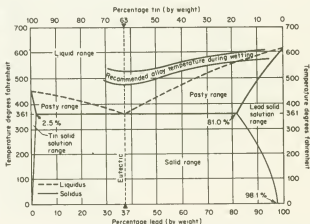
The term solder alloys covers a broad range of materials with greatest emphasis placed on compositions of tin and lead. The tin lead system of alloys has a general solidus temperature of 361°F. The eutectic composition, the alloy with a single sharp melting point and no plastic range, is 63% tin, 37% lead. This alloy is in widest use in the electronic industry.

The specific tin lead alloy selected is determined by the nature of the joining operation and the degree to which a plastic or "mushy" solder state can be tolerated or is desirable. Tin lead alloys with a tin content from 20% up through and including 97.5% have the same 361°F solidus line. Alloys containing lower percentages of tin have an increased solidus temperature. This is also true of tin antimony, tin silver, and lead silver alloys. The higher solidus line permits operation of the soldered part in higher ambient temperatures. It also permits sequential or piggy-back soldering. Where two soldering connections are to be made in areas very close to each other, the first joint can be made with one of the high-temperature alloys. When the second joint is made with an alloy in the normal tin lead system, the first joint will not be disturbed.

Solder Alloy Chart

Percent Tin	Percent Lead	Percent Silver	Percent Antimony	Temperature at which Solder Becomes Plastic		Temperature at which Solder Becomes Liquid	
				°C	°F	°C	°F
0	100			300	572	327	621
5	95			267.5	514	300	572
15	85			223	433	290	554
20	80			183	361	280	536
25	75			183	361	287	513
30	70			183	361	266	491
35	65			183	361	245	473
40	60			183	361	235	456
45	55			183	361	223	433
50	50			183	361	212	414
55	45			183	361	200	392
60	40			183	361	189	372
63	37			eutectic alloy*		183	361
65	35			183	361	186	367
70	30			183	361	191	376
75	25			183	361	195	383
80	20			183	361	201	394
85	15			183	361	207	404
90	10			183	361	214	417
95	5			183	361	222	432
97.5	2.5			183	361	227	441
100	0					232	460
25	63		2	187	369	237	459
20	78.7	1.3		181	358	276	529
27	70	3		178	352	263	487
	95	5		306	581	360	680

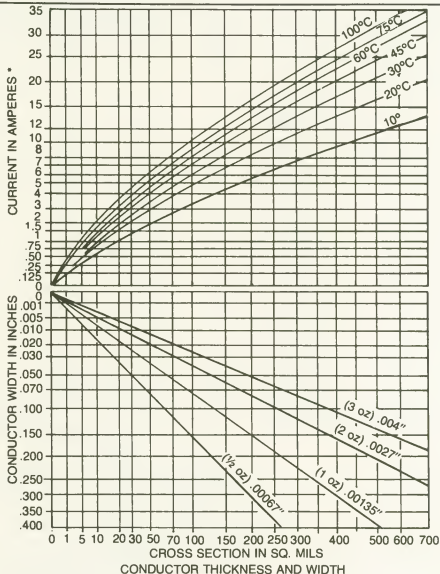
*A eutectic alloy is that composition of two or more metals that has one sharp melting point and no plastic range.



TRACK WIDTH OF PRINTED WIRING BOARDS

The two graphs are used to determine the current-carrying capacity and sizes of etched copper conductors (tracks) for various temperature rises above ambient. To use the charts, enter the top chart from the left at the current value which is anticipated, to the point where it interrupts the applicable copper temperature-rise curve. Then, proceed vertically down to the second chart to the appropriate weight (the weight of one square foot of copper of a given thickness) slanted line, and proceed left to determine the minimum track width.

FOR EXAMPLE: To carry 10 amperes and not exceed a 20°C rise above ambient requires a 0.100-inch wide conduct of 2-ounce copper track.



*Based on 1/16 inch boards. For thicker boards, derate by 15%.

DEFINED VALUES AND PHYSICAL CONSTANTS

A consistent set of physical values has been adapted by the National Bureau of Standards. The values presented below are at least as accurate as any others available, and have the advantage of being self-consistent, thus preventing the necessity of having to make a choice between different answers derived in different ways.

Fundamental Constants

Compiled by E. R. Cohen and B. N. Taylor under the auspices of the CODATA Task Group on Fundamental Constants. This set has been officially adopted by CODATA and is taken from J. Phys. Chem. Ref. Data, Vol. 2, No. 4, p. 663 (1973) and CODATA Bulletin No. 11 (December 1973).

Quantity	Symbol	Numerical Value *	Uncert. (ppm)	SI †	← Units →	cgs ‡
Speed of light in vacuum	c	299792458(1.2)	0.004	m·s ⁻¹		10 ¹⁰ cm·s ⁻¹
Permeability of vacuum	μ_0	4π =12.5663706144		10 ⁻⁷ H·m ⁻¹ 10 ⁻⁷ H·m ⁻¹		
Permittivity of vacuum, 1/ $\mu_0 c^2$	ϵ_0	8.854187818(71)	0.008	10 ⁻¹⁸ F·m ⁻¹		
Fine-structure constant, [$\mu_0 c^2/4\pi](e^2/\hbar c)$	α	7.2973506(60)	0.82	10 ⁻³		10 ⁻³
Elementary charge	e	1.6021892(46)	2.9	10 ⁻¹⁹ C		10 ⁻¹⁹ esu
Planck constant	h	4.803242(14)	2.9	10 ⁻³⁴ J·s		10 ⁻³⁴ erg·s
Avogadro constant	N_A	6.022045(31)	5.1	10 ²³ mol ⁻¹		10 ²³ mol ⁻¹
Atomic mass unit, 10 ⁻³ kg·mol ⁻¹ N_A^{-1}	u	1.6605655(86)	5.1	10 ⁻³⁷ kg		10 ⁻³⁶ g
Electron rest mass	m_e	9.109534(47)	5.1	10 ⁻³¹ kg		10 ⁻³⁰ g
Proton rest mass	m_p	5.4858026(21)	0.38	10 ⁻²⁷ kg		10 ⁻²⁷ g
Ratio of proton mass to electron mass	m_p/m_e	1.6726485(86)	5.1	10 ⁻³¹ kg		10 ⁻³⁰ g
Neutron rest mass	m_n	1.007276470(11)	0.38	u		u
Electron charge to mass ratio	e/ m_e	1836.15152(70)	0.38	10 ⁻¹⁷ kg		10 ⁻¹⁶ g
Magnetic flux quantum, [c] ⁻¹ (hc/2e)	Φ_0	1.6749543(86)	5.1	10 ⁻³⁷ kg		10 ⁻³⁶ g
Josephson frequency- voltage ratio	2e/h	1.008665012(37)	0.037	u		u
Quantum of circulation	$h/2m_e$	1.7588047(49)	2.8	10 ⁻¹¹ C·kg ⁻¹		10 ⁻¹⁰ erg·g ⁻¹
Faraday constant, $N_A e$	F	5.272764(15)	2.8	10 ¹¹ C·kg ⁻¹		10 ¹¹ esu·g ⁻¹
Rydberg constant, [$\mu_0 c^2/4\pi](m_e e^4/4\pi\hbar^2 c)$	R_∞	2.0678506(54)	2.6	10 ⁻¹⁵ Wb		10 ⁻¹⁵ G·cm ³
Bohr radius, [$\mu_0 c^2/4\pi](\hbar^2/m_e e^2)=a/4\pi R_\infty$	a_0	4.135701(11)	2.6	10 ⁻¹³ J·s·C ⁻¹		10 ⁻¹³ erg·s·esu ⁻¹
Classical electron radius, [$\mu_0 c^2/4\pi](e^2/m_e c^2)=a/4\pi R_\infty$	r_e	1.3795215(36)	2.6	10 ⁻¹⁵ Hz·V ⁻¹		10 ⁻¹⁵ erg·s·esu ⁻¹
Thomson cross section, (8/3) πr_e^2	σ_T	4.835939(13)	2.6	10 ⁻¹⁶ m ²		10 ⁻¹⁶ cm ²
Free electron g-factor, or electron magnetic moment in Bohr magnetons	$g_e/2=\mu_e/\mu_B$	3.6369455(60)	1.6	10 ⁻¹⁶ J·s·kg ⁻¹		erg·s·g ⁻¹
		7.273891(12)	1.6	10 ⁻¹⁶ J·s·kg ⁻¹		erg·s·g ⁻¹
		9.648456(27)	2.8	10 ⁻¹⁶ C·mol ⁻¹		10 ¹⁹ esu·mol ⁻¹
		2.8925342(82)	2.8	10 ⁻¹⁶ C·mol ⁻¹		10 ¹⁹ esu·mol ⁻¹
		1.097373177(83)	0.075	10 ⁻¹⁶ m ⁻¹		10 ⁻¹⁶ cm ⁻¹
		5.2917706(44)	0.82	10 ⁻¹¹ m		10 ⁻¹¹ cm
		2.8179380(70)	2.5	10 ⁻¹³ m		10 ⁻¹³ cm
		0.6652448(33)	4.9	10 ⁻³¹ m ³		10 ⁻³¹ cm ³
		1.0011596567(35)	0.0035			

Quantity	Symbol	Numerical Value * Uncert. (ppm)	SI †	← Units →	cgs ‡
Free muon g-factor, or muon magnetic moment in units of $[e\hbar/2m_\mu c]$	$g_\mu/2$	1.00116616(31) 0.31			
Bohr magneton, $[e\hbar/2m_e c]$	μ_B	9.274078(36) 3.9	10^{-34} J-T ⁻¹		10^{-11} erg-G ⁻¹
Electron magnetic moment	μ_e	9.284832(36) 3.9	10^{-34} J-T ⁻¹		10^{-11} erg-G ⁻¹
Gyromagnetic ratio of protons in H ₂ O	γ'_p	2.6751301(75) 2.8	10^8 s ⁻¹ ·T ⁻¹		10^4 s ⁻¹ ·G ⁻¹
γ'_p corrected for diamagnetism of H ₂ O	$\gamma'_p/2\pi$	4.257602(12) 2.8	10^7 Hz-T ⁻¹		10^4 Hz-G ⁻¹
Magnetic moment of protons in H ₂ O in Bohr magnetons	μ'_p/μ_B	2.6751987(75) 2.8	10^3 s ⁻¹ ·G ⁻¹		10^4 s ⁻¹ ·G ⁻¹
Proton magnetic moment in Bohr magnetons	μ_p/μ_B	4.257711(12) 2.8	10^3 Hz-T ⁻¹		10^4 Hz-G ⁻¹
Ratio of electron and proton magnetic moments	μ_e/μ_p	1.52099322(10) 0.066	10^{-3}		10^{-3}
Proton magnetic moment	μ_p	1.521032209(16) 0.011	10^{-3}		10^{-3}
Magnetic moment of protons in H ₂ O in nuclear magnetons	μ'_p/μ_N	658.2106880(66) 0.010			
μ'_p/μ_N corrected for diamagnetism of H ₂ O	μ'_p/μ_N	1.4106171(55) 3.9	10^{-13} J-T ⁻¹		10^{-11} erg-G ⁻¹
Nuclear magneton, $[e\hbar/2m_p c]$	μ_N	2.7927740(11) 0.38			
Ratio of muon and proton magnetic moments	μ_μ/μ_p	2.7928456(11) 0.38			
Muon magnetic moment	μ_μ	5.050824(20) 3.9	10^{-11} J-T ⁻¹		10^{-11} erg-G ⁻¹
Ratio of muon mass to electron mass	m_μ/m_e	206.76865(47) 2.3	10^{-13} J-T ⁻¹		10^{-11} erg-G ⁻¹
Muon rest mass	m_μ	1.883566(11) 5.6	10^{-31} kg		10^{-28} g
Compton wavelength of the electron, $h/m_e c = \alpha^2/2R_\infty$	λ_C	0.11342920(26) 2.3	u		u
Compton wavelength of the proton, $h/m_p c$	$\lambda_{C,p}$	2.4263089(40) 1.6	10^{-15} m		10^{-13} cm
Compton wavelength of the neutron, $h/m_n c$	$\lambda_{C,n}$	3.8615905(64) 1.6	10^{-15} m		10^{-13} cm
Compton wavelength of the electron, $h/m_e c$	$\lambda_{C,e}$	1.3214099(22) 1.7	10^{-15} m		10^{-13} cm
Compton wavelength of the proton, $h/m_p c$	$\lambda_{C,p}$	2.1030892(36) 1.7	10^{-15} m		10^{-13} cm
Compton wavelength of the neutron, $h/m_n c$	$\lambda_{C,n}$	1.3195909(22) 1.7	10^{-15} m		10^{-13} cm
Molar volume of ideal gas at s.t.p.	V_m	2.1001941(35) 1.7	10^{-15} m		10^{-13} cm
Molar gas constant, $V_m p_0/T_0$ ($T_0=273.15$ K; $p_0=101325$ Pa=1 atm)	R	22.41383(70) 31	10^{-3} m ³ ·mol ⁻¹		10^4 cm ³ ·mol ⁻¹
Boltzmann constant, R/N_A	k	8.31441(26) 31	J·mol ⁻¹ ·K ⁻¹		10^7 erg·mol ⁻¹ ·K ⁻¹
Stefan-Boltzmann constant, $\pi^2 k^4/60\hbar^3 c^2$	σ	8.20568(26) 31	10^{-3} m ² ·atm·mol ⁻¹ ·K ⁻¹		10 cm ² ·atm·mol ⁻¹ ·K ⁻¹
First radiation constant, $2\pi hc^2$	c_1	1.380662(44) 32	10^{-13} J·K ⁻¹		10^{-13} erg·K ⁻¹
Second radiation constant, hc/k	c_2	5.67032(71) 125	10^{-3} W·m ⁻² ·K ⁻⁴		10^{-8} erg·s ⁻¹ ·cm ⁻² ·K ⁻⁴
Gravitational constant	G	3.741832(20) 5.4	10^{-13} W·m ²		10^{-8} erg·cm ³ ·s ⁻¹
Ratio, kx-unit to ångström, $\lambda = \lambda(\text{Å})/\lambda(\text{kxu})$	Λ	1.438786(45) 31	10^{-3} m·K		cm·K
Ratio, Å* to ångström, $\Lambda^* = \lambda(\text{Å})/\lambda(\text{Å}^*)$	Λ^*	6.6720(41) 615	10^{-11} m ³ ·s ⁻² ·kg ⁻¹		10^{-8} cm ³ ·s ⁻² ·g ⁻¹
Ratio, Å* to ångström, $\Lambda^* = \lambda(\text{Å})/\lambda(\text{Å}^*)$	Λ^*	1.0020772(54) 5.3			
Ratio, Å* to ångström, $\Lambda^* = \lambda(\text{Å})/\lambda(\text{Å}^*)$	Λ^*	1.0000205(56) 5.6			

ENERGY CONVERSION FACTORS AND EQUIVALENTS

Quantity	Symbol	Numerical Value *	Units	Uncert. (ppm)
1 kilogram (kg·c ²)		8.987551786(72)	10 ¹⁶ J	0.008
		5.609545(16)	10 ²³ MeV	2.9
1 Atomic mass unit (u·c ²)		1.4924418(77)	10 ⁻¹⁰ J	5.1
		931.5016(26)	MeV	2.8
1 Electron mass (m _e ·c ²)		8.187241(42)	10 ⁻¹¹ J	5.1
		0.5110034(14)	MeV	2.8
1 Muon mass (m _μ ·c ²)		1.6928648(96)	10 ⁻¹¹ J	5.6
		105.65948(35)	MeV	3.3
1 Proton mass (m _p ·c ²)		1.5033015(77)	10 ⁻¹⁰ J	5.1
		938.2796(27)	MeV	2.8
1 Neutron mass (m _n ·c ²)		1.5053738(78)	10 ⁻¹⁰ J	5.1
		939.5731(27)	MeV	2.8
1 Electron volt		1.6021892(46)	10 ⁻¹⁹ J	2.9
			10 ⁻¹⁸ erg	2.9
1 eV/h		2.4179696(63)	10 ¹⁴ Hz	2.6
1 eV/hc		8.065479(21)	10 ⁸ m ⁻¹	2.6
			10 ³ cm ⁻¹	2.6
1 eV/k		1.160450(36)	10 ⁴ K	31
Voltage-wavelength conversion, hc		1.986478(11)	10 ⁻²⁵ J·m	5.4
		1.2398520(32)	10 ⁻⁶ eV·m	2.6
			10 ⁻⁴ eV·cm	2.6
Rydberg constant	R _∞ hc	2.179907(12)	10 ⁻¹⁸ J	5.4
			10 ⁻¹¹ erg	5.4
		13.605804(36)	eV	2.6
	R _∞ c	3.28984200(25)	10 ¹⁵ Hz	0.075
	R _∞ hc/k	1.578885(49)	10 ⁴ K	31
Bohr magneton	μ _B	9.274078(36)	10 ⁻²⁴ J·T ⁻¹	3.9
		5.7883785(95)	10 ⁻⁵ eV·T ⁻¹	1.6
	μ _B /h	1.3996123(39)	10 ¹⁵ Hz·T ⁻¹	2.8
	μ _B /hc	46.68604(13)	m ⁻¹ ·T ⁻¹	2.8
			10 ⁻³ cm ⁻¹ ·T ⁻¹	2.8
	μ _B /k	0.671712(21)	K·T ⁻¹	31
Nuclear magneton	μ _N	5.05824(20)	10 ⁻²⁷ J·T ⁻¹	3.9
		3.1524515(53)	10 ⁻⁶ eV·T ⁻¹	1.7
	μ _N /h	7.622532(22)	10 ⁸ Hz·T ⁻¹	2.8
	μ _N /hc	2.5426030(72)	10 ⁻³ m ⁻¹ ·T ⁻¹	2.8
			10 ⁻⁴ cm ⁻¹ ·T ⁻¹	2.8
	μ _N /k	3.65826(12)	10 ⁻⁴ K·T ⁻¹	31

* Note that the numbers in parentheses are the one standard-deviation uncertainties in the last digits of the quoted value computed on the basis of internal consistency, that the unified atomic mass scale ¹²C=12 has been used throughout, that u=atomic mass unit, C=coulomb, F=farad, G=gauss, H=hertz, Hz=hertz=cycle/s, J=joule, K=kelvin (degree Kelvin), Pa=pascal=N·m⁻², T=tesla (10⁴ G), V=volt, W=watt, Wb=weber=T·m², and W=watt. In cases where formulas for constants are given (e.g., R_∞), the relations are written as the product of two factors. The second factor, in parentheses, is the expression to be used when all quantities are expressed in cgs units, with the electron charge in electrostatic units. The first factor, in brackets, is to be included only if all quantities are expressed in SI units. We remind the reader that with the exception of the auxiliary constants which have been taken to be exact, the uncertainties of these constants are correlated, and therefore the general law of error propagation must be used in calculating additional quantities requiring two or more of these constants.

† Quantities given in u and atm are for the convenience of the reader; these units are not part of the International System of Units (SI).
‡ In order to avoid separate columns for "electromagnetic" and "electrostatic" units, both are given under the single heading "cgs Units." When using these units, the elementary charge *e* in the second column should be understood to be replaced by *e_m* or *e_s*, respectively.

APPROXIMATE CAPACITANCE OF CONDUCTORS (pt/inch)

Spacing (in.)	XXXP	Material Melamine	Teflon
1/32	1.05	1.25	0.33
1/16	0.85	1.10	0.26
1/8	0.72	0.90	0.22

APPROXIMATE RESISTANCE OF CONDUCTORS (ohms/inch)

Based on 100% conductivity of copper at 20°C

$$R = \frac{0.000503}{w} \text{ for 1 ounce copper}$$

$$R = \frac{0.000226}{w} \text{ for 2 ounce copper}$$

$$R = \frac{0.000135}{w} \text{ for 3 ounce copper}$$

w = conductor width in inches

VELOCITY OF SOUND IN SOLIDS, GASES, AND LIQUIDS

Velocity of Sounds in Solids

Medium	Velocity (ft./sec)	Medium	Velocity (ft./sec)
Aluminum	17,192	Magnesium	16,079
Brass	11,221	Nickel	15,615
Cadmium	7,874	Quartz Glass	17,618
Copper	11,745	Silver	8,661
Cork	1,640	Steel	16,569
Iron	16,962	Tin	8,957

Velocity of Sound in Gases at 0°C

Medium	Symbol	Velocity (ft./sec)
Air		1,087
Ammonia	NH ₃	1,361
Argon	A	1,046
Carbon Monoxide	CO	1,106
Carbon Dioxide	CO ₂	881 (above 100 Hz)
Chlorine	CL	674
Ethylene	C ₂ H ₄	1,040
Helium	He	3,182
Hydrogen	H ₂	4,165
Methane	CH ₄	1,417
Neon	Ne	1,427
Nitric Oxide	NO	1,066
Nitrous Oxide	N ₂ O	859
Nitrogen	N ₂	1,096
Oxygen	O ₂	1,041

Velocity of Sounds in Liquids

Medium	Temperature (°C)	Velocity (ft./sec)
Water (fresh)	17	4,691
Water (sea)	15	4,937
Alcohol (ethyl)	20	3,838
Benzene	20	4,330
Ether (ethyl)	20	3,313
Glycerin	20	6,299
Mercury	20	4,757

RELAY CONTACT CODE

This is the letter code adapted by the American Standards Association and by the National Association of Relay Manufacturers to describe relay contacts.



















Other standard contact symbols

Form	IEC, JIC and NMTBA symbol	Other IEC symbols
A		OR
B		OR
C		OR
D		

*LETTER ABBREVIATIONS

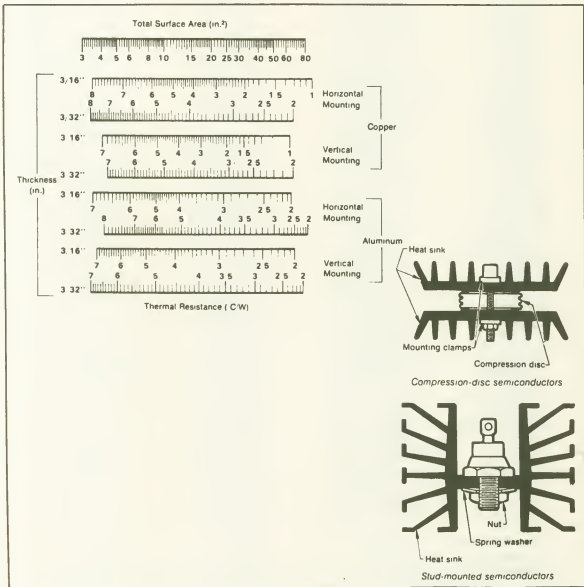
B: BREAK
 C: CLOSED
 D: DOUBLE
 M: MAKE
 N: NORMALLY
 O: OPEN
 P: POLE
 S: SINGLE
 T: THROW

EXAMPLE: SP ST NC OB is read as Single Pole, Single Throw, Normally Closed, Double Break

FORM	TERM	CONTACT CONFIGURATION	FORM	TERM	CONTACT CONFIGURATION
A	MAKE	 SP ST NO'	J	MAKE MAKE BREAK	
B	BREAK	 SP ST NC'	K	SP DT CENTER OFF	 SP DT NO'
C	BREAK MAKE (transfer)	 SP DT'	L	BREAK MAKE MAKE	
D	MAKE-BEFORE BREAK (continuity transfer)		U	DOUBLE MAKE CONTACT ON ARMATURE	
E	BREAK MAKE-BEFORE BREAK		V	DOUBLE BREAK CONTACT ON ARMATURE	
F	MAKE MAKE		W	DOUBLE BREAK DOUBLE MAKE CONTACT ON ARMATURE	
G	BREAK BREAK		X	DOUBLE MAKE SP ST NO OM'	
H	BREAK BREAK MAKE		Y	DOUBLE BREAK SP ST NC DB'	
I	MAKE BREAK MAKE		Z	DOUBLE BREAK DOUBLE MAKE SP ST DB'	

HEAT-SINK THERMAL RESISTANCE CHART

Heat-sink thermal resistance can be determined with the accompanying chart. Values determined graphically are not as accurate as those found from thermal equations but are precise enough for most applications. To find thermal resistance, draw a vertical line from the scale for surface area to the scales for materials and read the corresponding thermal resistance. For example, a 3/16-in.-thick piece of horizontally mounted copper with a surface area of 15 in.² has a thermal resistance of approximately 4.1°C/W. And a 3/32-in.-thick piece of vertically mounted copper with a surface area of 25 in.² has a thermal resistance of approximately 3.1°C/W. Note that vertical heatsinks have lower thermal resistances than horizontal sinks because convection provides increased heat dissipation.



FOREIGN VOLTAGE GUIDE

Following is an up-to-date guide to predominant electric voltages in foreign countries. In general, all references to 110 V apply to the range from 110 V to 160 V. References to 220 V apply to the range from 200 V to 260 V. Where 110/220 V is indicated, voltage varies within the country, depending on location.

Aden	220V	Dominica	220V
Afghanistan	220V	Dominican Rep.	110/220V
Algeria	110/220V	Ecuador	110/220V
Angola	220V	Egypt	110/220V
Anguilla	220V	El Salvador	110V
* Antigua	110/220V	Ethiopia	110/220V
† Argentina	220V	† Fiji	220V
Aruba	110V	Finland	220V
†† Australia	220V	France	110/220V
* Austria	220V	French Guiana	110/220V
Azores	110/220V	Gabon	220V
Bahamas	110/220V	Gambia	220V
Bahrain	220V	*† Germany	110/220V
Bangladesh	220V	Ghana	220V
Barbados	110/220V	Gibraltar	220V
Belgium	110/220V	* Great Britain	220V
Bermuda	110/220V	† Greece	110/220V
Bhutan	220V	Greenland	220V
Bolivia	110/220V	* Grenada	220V
Bonaire	110/220V	Grenadines	220V
* Botswana	220V	* Guadeloupe	110/220V
† Brazil	110/220V	Guatemala	110/220V
Brit. Honduras	110/220V	Guinea	220V
Brit. Virgin I.	110/220V	Guyana	110/220V
Bulgaria	110/220V	Haiti	110/220V
Burma	220V	Honduras	110/220V
Burundi	220V	* Hong Kong	220V
Cambodia	110/220V	Hungary	220V
Cameroon	110/220V	Iceland	220V
Canada	110V	† India	220V
Canal Zone	110/220V	Indonesia	110/220V
Canary I.	110/220V	Iran	220V
Cayman I.	110V	Iraq	220V
Cen. African Rep.	220V	* Ireland	220V
Chad	220V	Isle of Man	220V
* Channel I. (Brit)	220V	Israel	220V
† Chile	220V	Italy	110/220V
† China	220V	Ivory Coast	220V
Colombia	110V	* Jamaica	110/220V
Costa Rica	110/220V	Japan	110V
Cuba	110V	Jordan	220V
Curacao	110V	* Kenya	220V
* Cyprus	220V	Korea	110V
Czechoslovakia	110/220V	Kuwait	220V
Dahomey	220V	Laos	110/220V
Denmark	220V	Lebanon	110/220V

Lesotho	220V	Samoa	110/220V
Liberia	110/220	St. Barthelemy	220V
Libya	110/220V	St. Eustatius	110/220V
• Liechtenstein	220V	* St. Kitts	220V
Luxembourg	110/220V	* St. Lucia	220V
Macao	110/220V	St. Maarten	110/220V
† Madeira	220V	St. Vincent	220V
Majorca	110V	Saudi Arabia	110/220V
Malagasy Rep.	220V	* Scotland	220V
* Malawi	220V	Senegal	110V
* Malaysia	220V	Seychelles	220V
Malì	110/220V	Sierra Leone	220V
Malta	220V	* Singapore	110/220V
Martinique	110/220V	Somalia	110/220V
Mauritania	220V	* South Africa	220V
Mexico	110/220V	* Spain	110/220V
Monaco	110/220V	Sri Lanka (Ceylon)	220V
Montserrat	220V	Sudan	220V
Morocco	110/220V	Surinam	110/220V
Mozambique	220V	Swaziland	220V
Nepal	220V	† Sweden	110/220V
* Netherlands	110/220V	* Switzerland	110/220V
Neth. Antilles	110/220V	Syria	110/220V
* Nevis	220V	Tahiti	110V
New Caledonia	220V	Taiwan	110/220V
New Hebrides	220V	Tanzania	220V
† New Zealand	220V	Thailand	220V
Nicaragua	110V	Tobago	110/220V
Niger	220V	Togo	110/220V
* Nigeria	220V	Tonga	220V
* Northern Ireland	220V	Trinidad	110/220V
Norway	220V	Tunisia	110/220V
Okinawa	110V	Turkey	110/220V
Oman	220V	Turks & Caicos I.	110V
Pakistan	220V	Uganda	220V
Panama	110V	United Arab Emirates	220V
Papua New Guinea	220V	Upper Volta	220V
† Paraguay	220V	Uruguay	220V
Peru	220V	USA	110V
Philippines	110/220V	USSR	110/220V
Poland	220V	U.S. Virgin I.	110V
Portugal	110/220V	Venezuela	110V
Puerto Rico	110V	Vietnam	110/220V
Qatar	220V	* Wales	220V
* Rhodesia	220V	Yemen	220V
Romania	110/220V	* Yugoslavia	220V
Rwanda	220V	Zaire	220V
Saba	110/220V	Zambia	220V

*Denotes countries in which plugs with 3 square pins are used (in whole or part) †Requires plug with angled blades

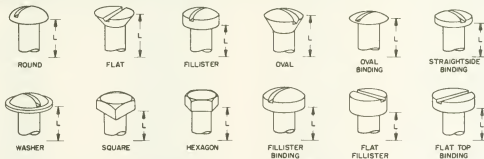
†Countries using dc in certain areas

*Countries with recessed outlets

(Reprinted from "Foreign Electricity Is No Deep Dark Secret," courtesy of Franzus Company Inc.)

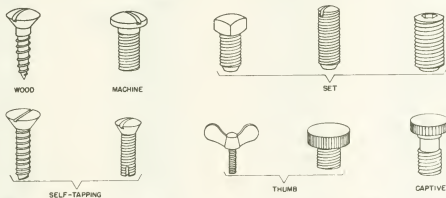
TYPICAL HARDWARE USED IN ELECTRONIC EQUIPMENT

HEAD TYPES FOR BOLTS AND SCREWS



LENGTHS ARE SPECIFIED BETWEEN POINTS INDICATED BY ARROWS.

SCREW TYPES



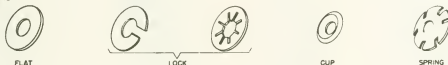
SET SCREWS



RECESSED DRIVES



WASHERS



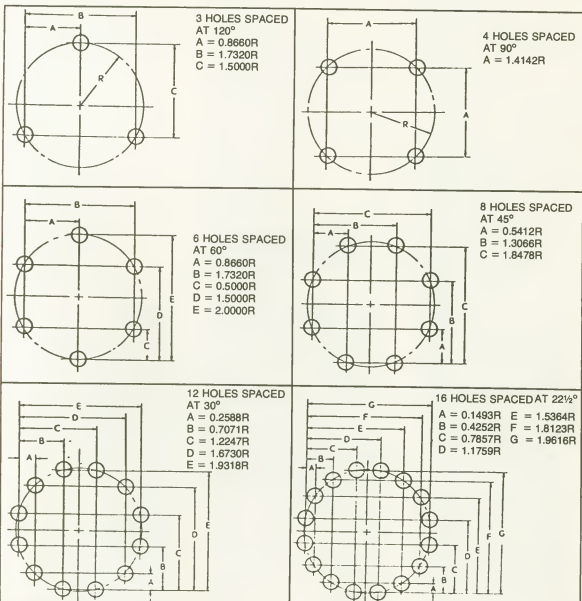
NUTS



COORDINATES FOR EQUALLY SPACED HOLES

It is sometimes necessary to determine the x and y coordinates of a circle divided into an equal number of parts. The following table can be used directly, or it can serve as a crosscheck against answers obtained by normal trigonometric methods.

FOR EXAMPLE: A circle that has a radius of 5.0 cm and contains 4 holes spaced at 90° . Determine the distance between their centers. $A = 1.4142R = 1.4142 (5.0) = 7.07$ cm.



(Reprinted from "Coordinates for Equally Spaced Holes, *Design News*, September 22, 1975, page 108, courtesy Design News.)

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ISBN 0-8306-1538-5

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